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A large, abstract graphic composed of numerous thin, white, curved lines that sweep across the upper half of the cover, creating a sense of motion and flow.

SEFI Handbook on Teaching Transferable Competencies and Skills in Engineering

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Editors: Gillian Saunders-Smiths, Lynn Van den Broeck, Thies Johannsen

Colophon

SEFI Handbook on Teaching Transferable Competencies and Skills in Engineering

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This book has been peer reviewed. The peer review was open. The author and the publisher would like to thank the reviewers for their time and effort.

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Preface

Gillian Saunders-Smiths, Lynn Van den Broeck, and Thies Johannsen

The handbook that lies before you finds its origins in a group of engineering educators who are passionate about teaching and researching competencies and skills in engineering education, in particular transferable competencies and skills, defined as competencies and skills *“that are needed to adapt to various life contexts and that people can potentially transfer to different social, cultural or work settings”* (UNICEF, 2022, p. 3)

All of us are involved in SEFI, the European Society for Engineering Education. SEFI, founded in 1973, is a non-profit international organisation and is seen as the largest network of engineering education players in Europe. Among SEFI members are institutions of higher engineering education, educators, students, but also companies and other international associations and societies involved in the field of engineering education. The mission of SEFI is *“to contribute to the development and the improvement of engineering education in Europe, to emphasise the need for and to strengthen the image of both engineering education and engineering education professionals in society”* (SEFI, n.d.).

We came together as members of the SEFI Special Interest Group (SIG) on Engineering Skills. In addition to organizing workshops and meeting at the SEFI annual conference, this SIG meets monthly online to undertake a host of activities to facilitate engineering educators, learning and curriculum developers, and engineering education researchers such as yourselves. The aim of these activities is to share ideas and experiences, engage in collaborations, discuss future pathways in learning skills whilst learning from and with each other to improve the teaching of skills in engineering education. Examples of such activities are webinars on skills and the SEFI podcast. In addition, the SIG has the ambition to influence policy on skills in engineering education by writing position papers on this issue. The first SEFI position paper on engineering skills was published in 2016 (SEFI, 2016); the latest was published in 2025 (SEFI, 2025).

In one such (online) meeting, after the annual SEFI conference in 2023 in Dublin, the suggestion was made to share our combined experiences in teaching skills beyond the confines of the SEFI community. Inspired by the then ongoing work on the *Routledge International Handbook on Engineering Ethics Education* (Chance et al., 2024), the suggestion was made to publish a handbook on teaching transferable competencies and skills in engineering education, as those present at the meeting felt there was a need for such a handbook. To our knowledge no such handbook exists that looks at transferable competencies and skills. At that time, we, Gillian Saunders-Smiths of Delft University of Technology in the Netherlands and Lynn Van den Broeck of KU Leuven

in Belgium, put up our hands to put together a quick outline on paper to discuss at the next meeting — the rest, as they say, is history.

Aiming to launch the call for authors at the next SEFI annual conference in Lausanne in 2024, we set out to put the framework of the handbook together, initially joined by Esther Perea Borobio (Ravensbourne University London, UK), who had to take a step back in September 2024, with Thies Johannsen of TU Berlin in Germany volunteering to join the lead editor team instead. The background of this framework and its operationalisation within the handbook are discussed in detail in Chapters 1.1 and 1.5 respectively. The ambition to create a complete handbook quickly spiralled into a five-part, multi-chapter endeavour, which made us realise we needed to expand the editorial team. We attracted a total of ten associate Part editors, who all were either part of the SEFI Engineering Skills SIG or known to the lead editors as people with vast experience in teaching, curriculum development, and research in the area of transferable competencies and skills. You can find out more about each of us, as well as all the authors, in the Associate Editors and Author Biographies immediately following the Foreword by Professor Emanuela Tilley. The editors for Part 2 are Matteo di Benedetti, Helena Kovacs, Abel Nyamfene, and Kurt Coppens. Esther Perea Borobio together with Jenny Griffiths worked on Part 3, with Part 4 being overseen by Neil Cooke and Emanuela Tilley. Finally, Part 5 was overseen by Esther Ventura Medina and Natascha van Hattum-Janssen. Each Chapter was assigned an overseeing Part editor who kept in touch with the authors throughout the process, organizing meetings to kick start the process and answering any questions, with Lynn, Thies and Gillian acting as fallback. As the three lead editors, Gillian, Thies, and Lynn oversaw Part 1, with Thies also overseeing Part 2, Lynn Part 3 and Gillian Parts 4 and 5, to ensure both alignment and cross-fertilisation.

As Part 1, 'Transferable Competencies and Skills — Context and Challenges' sets the scene for the entire handbook and thus forms its backbone, we decided to invite experts in the fields of competencies and skills in engineering education, competency frameworks, and accreditation to write dedicated chapters on these topics. For the other chapters, we launched an online open call for interested authors at the SEFI Annual Conference at EPFL in Lausanne in early September 2024, based on the framework of the handbook. On 1 December 2024, when the call for interest closed, we had over 110 expressions of interest from more than 200 people from five different continents. Sadly, no contributions from Latin America were received. Each Part editor team went to work going through all submissions and this resulted in a total of 155 people from 56 different higher education institutes and professional organisations from 23 countries spread over five continents who have contributed to this 48-chapter handbook, which also includes a glossary and an index. Each chapter underwent two rounds of semi-open peer review and was reviewed by at least two authors from other chapters supplemented by additional volunteers as well as one of the editors, none of whom were from the same institution as the authors. All review results were discussed in online meetings with the entire team of editors, where joint decisions on whether to accept chapters and what changes to require within chapters were made. Before

publication, all chapters underwent copyright and similarity checks and were subjected to professional copyediting.

In line with the values on open science held by our own institutions, the conscious choice was made to publish the handbook as open as possible. We were delighted that TU Delft Open Publishing was willing to publish our handbook free of charge under a CC-BY license, which means that the copyright of each chapter remains with the authors. In addition to publishing support, they generously supported us with copyright services as well as partially funding the copy-editing services, with SEFI funding the remainder, and funding a teaching assistant to support the final compilation of the handbook. In addition to the online version of the handbook, physical copies of the handbook will be available at cost using TU Delft Open Publishing's print on demand service. We would like to emphasize that all authors, reviewers, and editors received no remuneration for their work, nor will they receive any royalties now that the work is published. This handbook has been made with 'sharing is caring' as a core value, as we strongly feel there should be as few barriers as possible to allow engineering educators to access material to help them shape their teaching of transferable competencies and skills.

This handbook has been almost three years in the making, and it has been an intensive but also very enjoyable process, allowing all of us to practice our own transferable competencies and skills in an environment of kind, like-minded people who all care deeply about engineering education and about transferable competencies and skills in particular. During these three years, many things good and bad happened that affected our authors and editors alike, both professionally and privately; sadly, at the time of writing this preface the world is a lot less peaceful than it was. Yet the journey over the past three years has convinced us as lead editors more than ever of the importance of mastering transferable competencies and skills as essential means in working together on this Earth in harmony with each other and the world around us. The sometimes-challenging road leading to this handbook has shown us that when we collaborate with perseverance and resilience, communicate with mutual respect, actively listen to each other, and reflect on ourselves whilst working towards a common goal with shared values on improving the education of engineers, we can contribute our bit to a better future. Our journey has not only been fun, but also fruitful. It has led us to tangible positive results, great memories, and true collegiality and friendship across the globe in line with the SEFI values of being inclusive, engaged and responsible, supporting and respecting diversity, equality, and different cultures without bias. This journey has offered us hope and faith for the future.

As with all projects such as this one, we have many people to thank. We would like to start with our partners and families. Without their patience, understanding and support, we could not have completed this project. We thank you with all our hearts. We would also like to express our thanks to all the people within the SEFI organisation for supporting us in this process, starting with Klara Ferdova, our SEFI Secretary General who helped us with organizing an authors' website, provided input for the cover, and liaised with conference organisers and the SEFI Board of Directors to make

that side of the process as smooth as possible. Thank you also to former SEFI president (2023-2025), Balász Nagy, for your enthusiasm and support in getting this process off the ground. Thanks also to our current president Emanuela Tilley, the SEFI Board of Directors, and the members of the SIG in Engineering Skills for your never-ending encouragement and support both morally and financially. In addition to being inspired by the *Routledge International Handbook on Engineering Ethics Education* (Chance et al., 2024), we also would like to thank two of its editors for all the help and advice they gave us during the process. Shannon Chance and Diana Martin, thank you for your time and wisdom! Furthermore, we would like to say thank you to the SEFI conference organizers in Lausanne who gave us the floor to launch our call for authors and to the SEFI organizers in Prague who not only facilitated the formal presentation of the published handbook but also invited us to give a keynote on transferable competencies and skills.

We are grateful for the many people at TU Delft Open Publishing who helped us through this process; first Roeland Loggen, Marcell Várkonyi, and Michiel Munnik for believing in this project when Gillian approached you almost two years ago. Thank you to Mira Buijst-Zhuk and in particular to Jacqueline Michielen-van Riet and Rixt Tuinstra, who went above and beyond in helping us in the final stages of this project and their many colleagues who assisted behind the scenes. Thank you also to Matteo di Benedetti for his fantastic, if not magical, spreadsheet skills that allowed us to keep track of it all without having to resort to special tools! Our TA, Friso Kroes, who created the cover design, and handled the vast DOI paperwork to get each chapter ready for publishing, thank you for keeping us sane. Thank you also to the IT support at KU Leuven who were willing to support us doing things in Microsoft Teams that had not been done before. Thank you to our copy-editor Saskia Roselaar who waded through each chapter, resolving any inconsistencies and errors and asking for clarifications where needed; you helped us so much, also for being fundamental in creating an index that allows the reader to find things even easier.

We would be remiss to not also acknowledge by name all the reviewers of this handbook, with many, but not all, also being authors, some of whom volunteered to do more than their fair share. For Part 1 they were: Adam Gibson, Anette Kolmos, Cristina Tripon, Darren Carthy, Deborah Bauder, Grant Penny, Greet Langie, Greg McNamara, Lucas Galey, Natalie Wint, Richard Lillington, Roger Hadgraft, Roger Hadgraft, Roger Penlington, and Virve Murto. Part 2 reviewers were: Alexandra Werth, Allison Hutchison, Amira Elnouty, Anna Maria Trzaskowska, Anthony Kadi, AraOluwa Adaramola, Brendan Hayes, Carl Anthony, Ceri Morris, Cindy Rottmann, Curwyn Mapaling, Dan Jiang, David Lowe, Eva Kalmar, Eve Hatten, Ewa Marjańska, Faith Nightingale, Homero Murzi, Ina Peters, Irene Josa, Jennifer Meyer, Jeroen Lievens, Jevgenija Prisutova, Joelyn de Lima, Jonathan Butcher, Juebei Chen, Khadijat Olorunlambe, Leah Ridgway, Lori Houghtalen, Maria Elena Oliveri, Mariam Makramalla, Martijn Wackers, Nathalie Al Kakoun, Olga Ioannou, Olga Pierrakos, Oscar van Putten, Oxana Lundström, Raffaella Manzini, Rebecca Yerworth, Rucha Joshi, Ryan Grammenos, Sabine Ammon, Sarah Jayne Hitt, Siqing Wei, Sonia M. Gómez Puente, Stephanie Fuchs, Stephanie Lunn, Stephen Marshall, Vicent Rutagangibwa,

and William Bennett. Part 3 was reviewed by Ademola Odunsi, Aled Davies, Arsam Nasrollahy Shiraz, Diana Martin, Eef Soete, Erik Vellinga, Erna Engelbrecht, Folashade A. Taiwo, Inês Direito, Johanna Naukkarinen, John Mitchell, Lydia Wilkinson, Natalie Wint, Nikita Hari, Peter Ruijten-Dodoiu, Pleun Hermsen, Rani Dujardin, Samantha Brunhaver, Shan Tuyaerts, Sofie Craps, Vladislav Krivoshchekov, Will Newton, and Yousef Jalali. The chapters of Part 4 were reviewed by Adam Gibson, Aida Guerra, Aziza Mahomed, Bettina Dahl Søndergaard, Cameron Mozafari, Mauryn C. Nweke, Claudia Favero, Dan Jiang, Gareth Thomson, Henrik Worm Routhe, Hua Wang, Jeremy Lindeck, Jette Holgaard, Jevgenija Prisutova, Meagan Kendall, Nichole Ramirez, Pilar Garcia Souto, Rehan Shah, Roger Gonzalez, Scott Strachan, Shannon A. Rios, Sonia M. Gómez Puente, Suzanne Lane, Tania Machet, Thomas Devaney, Tom Goldfinch, Traci Nathans-Kelly, Xiangyun Du, Yuan Lu, and Zena Green. Lastly, the reviewers for part 5 were Adesola Adetunji, Angeniet Kam, Ann-Kristin Winkens, Claire Lucas, Erna Engelbrecht, Ester Giménez-Carbó, Franch Maverick Lorilla, Jillian Seniuk Cicek, Kerrie Douglas, Natalie Wint, Rachel Figard, Remon Rooij, Sally Male, Siara Isaac, Tina Baradara, and Tinne De Laet.

That leaves us to thank all authors for their hard work, their fantastic chapters, and for putting up with our many emails with yet again new instructions, templates, and forms. Without you there would be no handbook! Finally, we as lead editors would like to thank our ten wonderful associate editors for a great collaboration. Dear Abel, Emanuela, Esther, Esther, Helena, Jenny, Kurt, Matteo, Natascha, and Neil, it has been a truly wonderful journey we went on together, which we will always treasure. We truly hope we will have the opportunity to work together again in the future.

In closing, we would like to address you, the reader of this handbook. We hope this handbook, that has been made with passion and love for our field, will fill you with joy and inspiration for teaching transferable competencies and skills. We would like to help you reach our shared goal of providing students all over the globe with the best engineering education we can provide to help our graduates find their way in life and leave this world a little better than they found it. Happy reading!

Gillian Saunders-Smiths, Lynn Van den Broeck, and Thies Johannsen

Lead editors SEFI Handbook on Teaching Transferable Competencies and Skills in Engineering Education

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AI statement

During the preparation of this preface the authors did not make use of any AI tools.

Foreword

Emanuela Tilley

As President of the European Society for Engineering Education (SEFI), and as a long-standing member of this vibrant, flourishing, and welcoming educational community, it is a deeply personal honour to write these words as an introduction to our SEFI *Handbook on Transferable Competencies and Skills in Engineering Education*. This handbook emerges at a particularly pivotal time for the engineering profession as well as higher education: a period shaped by rapid technological transformation, shifting societal expectations, and an urgent need to educate engineers who can act confidently, responsibly, and creatively in complex and dynamic environments. This mirrors the themes and an urgency highlighted in SEFI's 2025 *Position Paper on Engineering Skills*, which calls for a renewed focus on the integration of technical, transferable, and transdisciplinary (3T) skills to prepare engineers for our volatile, uncertain, complex, and ambiguous world.

My professional home for more than a decade has been University College London, where I have devoted my academic career to designing, implementing, and leading the Integrated Engineering Programme (IEP), a curriculum that embeds professional and transferable skills at the heart of engineering education. This work, supported, influenced, and strengthened by many within our SEFI community over the years, has reinforced my belief that transferable competencies and skills such as communication, leadership, ethical and cultural awareness, social responsibility, collaboration, reflection, project management, and adaptability, as well as creative, critical, anticipatory, and systems thinking explored throughout this book are not peripheral, but absolutely central to the formation of engineers who can shape a sustainable, equitable, and technologically responsible future. These convictions are deeply aligned with the motivation behind this handbook, which responds to the widespread need for coherent, evidence-based guidance for educators across Europe and beyond. Our SEFI handbook addresses challenges practitioners face in navigating the dispersed and at times inaccessible research landscape surrounding teaching and learning of transferable competencies and skills and aims to offer a practical, structured, and research-informed resource.

It has been my privilege not only to serve as SEFI President during the development of this landmark publication, but also to contribute directly as part of its editorial team. I have co-led Part 4 of the handbook, which focuses on embedding transferable competencies and skills at the curriculum level, bringing together current state-of-the-art practice and critical reflections on holistic programme design. This section complements the broader structure of the handbook, which spans a large list of contemporary competencies and skills, classroom practice, assessment, curriculum-level integration, and evaluation, with an architecture that touches on all aspects of

successful implementation and student attainment of skills-based and competency-focused education.

The handbook builds naturally upon the work of SEFI's Engineering Skills Special Interest Group (SIG), whose recent activities and workshops underscore the importance of coherent frameworks and collaborative approaches to competencies and skills integration. Together, these efforts reflect SEFI's continued commitment to supporting engineering educators, curriculum designers, and researchers in navigating the evolving expectations of engineering practice. The handbook answers a widely shared need across our classrooms and departments: a coherent, evidence-informed, practitioner-facing guide that gathers a dispersed research and practice landscape into a resource that is accessible and actionable for educators, curriculum leaders, and early career engineering education researchers. From its inception, the handbook was framed explicitly to meet that need and to make scholarship on transferable competencies and skills easier to find, interpret, and apply in context.

One of the handbook's strengths is its clear architecture, which spans the journey from foundational principles through classroom design, assessment, programme level integration, and evaluation. With its five parts — Part 1 (Transferable Competencies and Skills — Context and Challenges), Part 2 (Embedding Transferable Competencies and Skills in Your Classes), Part 3 (Assessing Transferable Competencies and Skills), Part 4 (Embedding Transferable Competencies and Skills at the Curriculum Level — the Current State of the Art), and Part 5 (Evaluating Needs, Interventions, and Outcomes of Transferable Competencies and Skills) — it is designed to support both the educator seeking a practical idea for their classroom on a Monday morning and the programme or curriculum leader designing and stewarding longer-term transformational change.

On a personal note, the IEP convinced me that students flourish when they are invited to be engineers early and often: to frame problems with stakeholders, design under uncertainty, argue with evidence, work across disciplinary languages, and design for and reflect on the ethical and societal implications of their decisions. Achieving that at scale requires aligned curricula, assessments that value what matters, initiatives that have students as co-partners in this journey to develop and strengthen their own learning, and a shared commitment among staff and educational leaders to keep learning. The 3T framing in SEFI's position work resonates with that lived experience. When technical excellence is amplified by transferable and transdisciplinary capabilities, graduates do more than secure employment; they help organisations and societies navigate complexity with integrity and imagination.

What you are reading and what the SEFI community offers to you is a pragmatic companion for the next stage of this journey we are on together. Whether you are refining a single module or redesigning an entire degree programme, you will find here a scaffold for moving from principle to practice, grounded in evidence, rich with examples, and oriented to impact. Read across the parts or dip in where your current challenges lie; either way, the throughline message is clear: the world needs engineers whose transferable competence and transdisciplinary awareness anchor and give

strength and depth to their technical acumen, equipping them to act with responsibility and courage in a rapidly changing world. This is the spirit of SEFI's 2025 Position Paper and the animating purpose of this handbook.

I invite you to engage critically and generously: adapt, test, and share what you learn, contribute to the continuing conversation, and join the community of practice that advances this agenda. On behalf of SEFI and the editorial team, I thank the many authors, reviewers, and colleagues whose expertise and dedication have made this handbook possible. May it become a trusted resource on your desk and a catalyst for the programmes and graduates our profession, and our world, need next.

Professor Emanuela Tilley

SEFI President

May 2026

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Part 1

Transferable

Competencies and Skills:

Context & Challenges

1.1

Introduction: Why We Need Transferable Competencies and Skills in Engineering Education

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Keywords: transferable competencies and skills, education policy, educational development, engineering curriculum, academic staff development, institutional transformation.

Engineering education today is increasingly challenged to provide students not only with technical expertise but also with transferable competencies and skills. In the introduction chapter to Part 1 of this SEFI Handbook on Teaching Transferable Competencies and Skills in Engineering, we trace current developments in the field and outline the rationale for our handbook, situating transferable competencies and skills as part of an inseparable triad of technical, transferable and transdisciplinary skills that should underpin any engineering degree. This chapter details the intended relevance for practitioners and our commitment to academic rigour, combined with practice through our evidence-informed approach. It further presents the overall structure of the handbook, highlights how the different parts of the handbook interrelate, and then zooms in on the chapters of Part 1, emphasising the practical value they provide for engineering education practitioners.

1 Setting the scene: why are transferable competencies and skills needed in engineering education?

Today, we live in a world facing complex challenges with global dimensions and major impacts on society. At the same time, these challenges are embedded in diverse and fast-moving transformation processes. These transformations include both new and potentially disruptive technologies on one side, and social changes on the other, such as how people interact, how we work, and how we learn. Think for instance of the development of the smartphone, which has significantly changed the way we work, learn, communicate, and interact with each other. This is often described as a sociotechnical transformation, where technical and social changes are inherently connected and involve many different stakeholders, new infrastructures, industries, and products as well as changing professional cultures and skills (Schot & Steinmueller, 2018).

Because these challenges are dynamic, complex, and not easily solved, they are often called 'wicked problems' (Buchanan, 1992; Mazzucato, 2018). We would also argue that we are facing a 'wicked situation', shaped by what is often described as a VUCA world — volatile, uncertain, complex, and ambiguous — combined with an emerging Fifth Industrial Revolution, or Industry 5.0 (Gürdür Broo et al., 2022; SEFI, 2025). Think, for instance, of the need to manufacture protective clothing and face masks locally during the COVID-19 pandemic, when the existing supply chains collapsed and an acute shortage occurred; the spreading of misinformation which is being accelerated through developments in Artificial Intelligence; or the accelerated use of cybertechnology in the commitment of increasingly global crimes and as a weapon in the increasing number of armed conflicts and the accompanying intelligence war.

From these new global challenges follows a demand for engineering education: we, as educators and practitioners, must prepare future engineers to face these challenges and to engage in collaborative, complex activities, both in their professional lives and as responsible citizens. To be able to act and shape their environment in the long term, our engineering students need the conditions that help them develop knowledge, attitudes, values, and abilities. In other words, they need transferable competencies and skills that allow them *"to become agile, adaptive learners and citizens equipped to navigate personal, academic, social, and economic challenges"* (UNICEF, 2019, p. 1).

Transferable competencies and skills are defined as *"competencies and skills that are needed to adapt to various life contexts and that people can potentially transfer to different social, cultural or work settings"* (UNICEF, 2022, p. 3). As such, transferable competencies and skills must be a part of engineering curricula if we are to prepare our students for the uncertain future that lies ahead of us.

2 Why a SEFI handbook? Our rationale and perspective

The idea of the importance of transferable competencies and skills must be part of any engineering curriculum laid the foundation for the decision to create this handbook. The handbook aims to facilitate, enable, and support engineering

educators and educational practitioners, such as yourself, in developing these transferable competencies and skills in students or, more generally, in all learners in engineering education.

In addition, because engineering activities reach into almost every part of modern societies, we strongly believe that a future-oriented engineering education must be practice-oriented and action-based. This is also reflected in various accreditation standards or programme outcomes for engineering degrees, such as the UK-SPEC (Engineering Council, 2020). To achieve this goal, embedding transferable competencies and skills, defined as *“competencies and skills ranging from the foundation and application of science to the applied mathematical and computational skills necessary to develop technical solutions in the sense of innovation and current demands”* (SEFI, 2025, p. 2), in engineering curricula is not optional; it is essential. These competencies can make a significant contribution to solving societal challenges.

To address these challenges in engineering curricula, recent developments in engineering education are showing a shift toward programmes that combine student-centred learning with curricula focused on major societal, environmental, and technological challenges (Graham, 2018), in which these competencies and skills are embedded alongside technical skills. These developments have even led to the argument that competencies and skills may become more important than formal degrees (Gürdür Broo et al., 2022). Whether or not you agree with this claim, a strong focus on student-centred learning and competency-based learning outcomes (Biggs & Tang, 2011) requires a continuous evolution of teaching and learning methods. These methods must keep up with changing demands and help learners develop the competencies and skills they need.

This evolution becomes visible in the growing number of engineering programmes that construct learning around real societal and technological challenges as a shift from *“first teach the fundamentals”* to *“first engage with the engineering problem”* (Hadgraft, 2017, p. 112). For instance, challenge-based or project-based curricula require students to integrate technical analysis with communication and teamwork.

These developments have been accompanied and supported by SEFI, the European Society for Engineering Education. SEFI’s mission is to *“support the advancement of engineering education by promoting innovative, inclusive, responsible, and forward-looking practices that are open, ethical, transparent, and sustainable”* (SEFI, n.d.). Within SEFI, the Special Interest Group (SIG) on Engineering Skills focuses specifically on analysing the current landscape of engineering competencies and skills to explore emerging trends, aiming to inform and inspire the engineering education community and keep programmes up to date.

As part of this aim, an initial position paper was published by SEFI in 2016 (SEFI, 2016). In response to the aforementioned rapid developments, a new position paper has been created with great effort and released by SEFI in 2025 (SEFI, 2025). This new publication draws a distinction between technical, transferable, and transdisciplinary competencies and skills, defining transdisciplinary competencies and

skills as “*competencies and skills that afford an outward facing, broader appreciation and active engagement with traditional and non-traditional sources of knowledge from both academic and non-academic domains. These encompass skills related to ethical decision-making, sustainability and social responsibility*” (SEFI, 2025, p. 2). While developing technical competencies and skills tends to align closely with the core expertise and disciplinary identities of engineering educators — and as technical competencies and skills are generally less challenging to teach due to clear accreditation and professional guidelines — integrating transferable and transdisciplinary competencies and skills into teaching practices often presents greater difficulty. This difficulty motivated us, the editors of the handbook, as active members of the SEFI SIG on Engineering Skills, and many engineering educators who, like us, actively implement transferable competencies and skills in our teaching, to create the handbook that you are now reading, focused specifically on transferable competencies and skills. As this handbook emerged from the SEFI SIG, it reflects a strong European perspective. Although the contributions are Europe-centred, they are globally applicable. Throughout the entire process, we have aimed to ensure relevance and compatibility across various contexts and conditions and ensured an evidence-informed approach.

To the best of our knowledge, this handbook on teaching transferable competencies and skills in engineering is the first of its kind. We hope that this handbook will offer you useful insights, practical guidance, illustrative examples, and constructive inspiration for engineering education practitioners.

3 Who the handbook is for and what it offers

This handbook has been created for you, engineering education practitioners of all disciplines, regardless of your specific subject area. It has been written by your peers, sharing what they wished someone had told them when they started. All our than 155 authors and editors are or have been involved in developing educational resources, teaching and often also researching transferable competencies and skills in engineering education. Our goal is to provide you with support that is relevant and useful across the full spectrum of engineering education when it comes to teaching transferable competencies and skills. Thus, this handbook is for you, if you are looking for inspiration and practical guidance on how to teach transferable competencies and skills in your classes. Allow us to take you through a bird’s eye view of each part of the book.

In Part 1, we start with setting the scene: introducing you to the concepts of transferable competencies and skills, how transferable competencies and skills development connects to wider frameworks and accreditation standards, and ending with an explanation of which transferable competencies and skills we have included in this handbook. If you are aiming to unlock hidden potential in your existing teaching and learning settings and would like to include these individual competencies and skills on a sound basis: We detail each of them in a dedicated chapter in Part 2. The handbook is also for you if you want to strengthen competency- and skills-oriented teaching, improve learning development, and revise existing or design new effective

assessments of these transferable competencies and skills (Part 3). If you want to go one step further and you are looking for inspiring examples or reference models at programme level: in Part 4 of this handbook, we provide global role-models from three continents that can support organisational development, programme planning, or curriculum design in your own institution. The closing part of this handbook, Part 5, explores how you can evaluate or research your learning outcomes when it comes to these transferable competencies and skills. Lastly, we have also added a glossary to the back of this handbook. As you read this handbook, you will come across many terms that you may be unfamiliar with within the context of this handbook. The glossary will allow you to look up any terms you may be unfamiliar with and how they are used within this handbook.

So why rely on our handbook? As stated before, we believe that transferable competencies and skills are an essential and intrinsic part of engineering education. Although no practical handbooks exist, there is an abundance of scientific literature. Yet, we are also aware that the relevant literature detailing research and practice of including transferable competencies and skills in engineering education is often difficult to identify and navigate. In addition, the body of research on transferable competencies and skills comes from a wide range of perspectives, with fundamentally different theoretical backgrounds (Kiesler, 2024). This field is broad, context-dependent, and not very accessible. We are also very aware of national and institutional contexts in which specific frameworks and requirements may limit the direct transferability of approaches reported in literature. This is why in this handbook we have provided you with contributions that are grounded in evidence and elaborated within their context but also demonstrate broader applicability across different settings. To do so, we have committed to an evidence-informed approach in which all contributions are rooted in empirical research, theoretically and methodologically rigorous, combined with practice, and with clear, direct, practical value for your work. All chapters have undergone two rounds of peer review to ensure robustness. You will find insights into relevant competencies and skills, assessment methods, and evaluation strategies, always presented in a way that supports their integration at module and programme level.

Therefore, if you are looking for a focused, practice-oriented, evidence-informed introduction to specific topics in the field of transferable competencies and skills, we dare to say this handbook is for you.

4 What to expect in Part 1 and how to use it

Part 1 of this handbook aims to provide context for the following parts. At the beginning of this chapter, we discussed why transferable competencies and skills matter in engineering education, who this book is for, and the contents of the five different parts of this handbook. However, this does not yet address the specific nature of competencies and skills as such.

These terms are often debated, as they resist a single, unified definition, making them difficult to handle clearly and consistently. This ambiguity poses a challenge for

competency- and skills-oriented engineering education. In Chapter 1.2, Sofie Craps, Helena Kovacs, Roger Hadgraft, Roger Penlington, and Anette Kolmos explore the concept of competencies and skills in detail. To this end, they address potential semantic pitfalls, trace the genealogy of the term, and place it within political and industrial discourses from an engineering education perspective. Following up on the latest SEFI Position Paper (2025), they explain how technical skills differ from transferable competencies and skills, and how these are linked to sector-specific interests, such as the demand for qualified professionals in industry. Importantly, they show that these discussions often leave little room for broader goals like personal development, even though such goals are deeply relevant. The situation becomes even more complex when regional and cultural factors enter the discussion. Here, the authors offer guidance to help you make sense of this complexity. They also outline key implications for engineering education research, arguing that terminology should be seen as a tool for theoretical reflection in both research and practice. For engineering education practitioners, this chapter is especially valuable. It supports a deeper theoretical understanding of teaching practices and provides a foundation for integrating competencies meaningfully into competence-based learning and teaching formats.

In Chapter 1.3, Grant Penny, Ann-Kristin Winkens, Neil Cooke, and Esther Perea Borobio explore existing skills and competency frameworks. To this end, they introduce the concept and explore what composes a framework. The authors then highlight that there is an abundance of frameworks, many of which are highly specific, while others overlap significantly. For engineering education practice, these frameworks are often insufficient as they tend to remain too general and offer little in the way of practical guidance or concrete references. Instead, due to their sometimes-abstract nature they often serve as a frame of reference to give orientation for strategic processes. To address this challenge, the authors propose a distinction between frameworks and taxonomies. They provide clear, practical advice for engineering education practitioners on how to engage with frameworks and which questions to ask to utilise them effectively in supporting learners' competency and skill development, as well as inform the complementing assessment. Moreover, if frameworks are linked to appropriate criteria and performance indicators, they can also be very useful for curriculum development. To help you navigate the field, the authors then present an overview of relevant frameworks in engineering education and, building on that, reflect on their practical value. They emphasise that the relevance of any framework must be determined in relation to the sociotechnical context, and that its usefulness may shift as conditions and goals change. In this regard, higher education institutions carry a particular responsibility, as they must prepare students for professional life, but without reducing education to market needs. Externally, frameworks can serve as a tool in organisational development while also providing guidance internally for staff in their roles as educators, curriculum developers, or in other capacities. Addressing the latter, the authors offer practical suggestions for how to make use of frameworks in a constructive way. They show

that frameworks are essentially tools, not checklists. They are there to support your work, not to be followed rigidly.

Chapter 1.4 explores the role of competencies and skills in the accreditation processes of engineering education. Darren Carthy, Richard Lillington, and José Carlos Quadrado begin by explaining what accreditation systems are and what purposes they serve, before focusing specifically on how transferable competencies and skills are addressed within engineering programmes. The chapter takes a close look at learning outcomes at both programme level and module level and introduces three key international accreditation standards. The authors examine the criteria applied in these standards and highlight their practical implications as they are formulated in the general principles of the International Engineering Alliance (IEA) and the European Network for Accreditation of Engineering Education (ENAE). They then discuss how these frameworks connect both technical and non-technical skills. Of particular value to practitioners is the section of this chapter that is dedicated to learning outcomes of educational programmes. The authors explain the concept and its relevance, outline the dimensions such outcomes may cover, compare different accreditation frameworks, and identify key challenges. This helps to clarify the role of learning outcomes for the accreditation process, with a focus on their use for engineering educational practice. Closely linked, the chapter addresses the importance of defining measurable criteria and explores the role of assessment within accreditation. The authors discuss different forms and methods of assessment, thereby emphasising the value of competence-based learning outcomes. These points are illustrated with real-world case studies from engineering programmes. In the final section, the authors discuss common pitfalls and challenges across accreditation systems and offer insights into emerging trends and future directions in the field. The chapter concludes with practical guidance and recommendations for engineering education practitioners by connecting future avenues of development to the realities of current practice by offering concrete, actionable insights.

Finally, in Chapter 1.5, we, the lead editors, together with Esther Perea Borobio, introduce the competency and skills framework used throughout this handbook. Building on the previous chapters, we zoom in from broader concepts to a concrete structure that underlies this publication and aligns with its aims. We begin by outlining the definition of transferable competencies and skills that underpins this handbook by drawing from the SEFI Position Paper (2025) and referencing the UNICEF definition on transferable competencies and skills (2019, 2022). This definition is then situated within the competency framework adopted here, with considerations of its historical references, disciplinary foundations, and professional relevance. We then describe how the framework was developed and explain the criteria used in selecting the competencies and skills featured in this handbook and its base, the UK-SPEC — The UK Standard for Professional Competence and Commitment (4th edition) — as published by the Engineering Council (2020). As a result of this process, three overarching themes are introduced:

- I. Responsibility, project management and leadership
- II. Communication and interpersonal skills
- III. Professional commitment and lifelong learning competencies

Each theme includes a set of specific competencies and skills, and for each of these, the handbook offers a definition and interpretation derived from literature and based in evidence. Subsequently, we reflect on which competencies and skills, as well as frameworks, were deliberately excluded. While the list of excluded competencies and skills is not exhaustive, it serves to ensure transparency regarding how we have reached decisions. We end the chapter with practical guidance on how to engage with the framework and the handbook from the perspective of engineering education practice.

5 In closing

To conclude, we would like to emphasise that the development of transferable competencies and skills in learners (and the educational practices that support them) is never linear or one-size-fits-all. It is always shaped by context, local conditions, and the people involved. For this reason, we invite you to use this handbook not only as a useful resource for your teaching and curriculum development, but also as a source of inspiration for your personal practice as an educator.

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AI statement

During the preparation of this work the authors did not make use of any AI tools.

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1.2

The Definition of Competency and Skills in an International Context

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The concepts of competencies and skills in engineering education are widely used yet inconsistently defined across regions, disciplines, and policy frameworks. This chapter explores the semantic, historical, political, cultural, and research dimensions of competencies, with a particular focus on Europe, while situating developments within a global context. It begins by tracing the utilitarian roots of competencies in psychology and vocational education, followed by an analysis of how supranational initiatives such as the Bologna Process, ENAEE, ABET, and CDIO have shaped their institutionalisation. The chapter then examines the broadening scope of competencies to include transferable skills, driven by globalisation, digitalisation, and pedagogical innovation. Regional and cultural diversity is shown to influence both terminology and enactment, complicating efforts toward harmonisation. Educational research reveals persistent conceptual ambiguity and methodological fragmentation, further challenging coherence. Through critical reflection, the chapter argues that competencies must be understood as a dynamic, context-dependent construct. Rather than seeking uniformity, engineering education should embrace plural definitions and foster reflexivity, transparency, and intercultural sensitivity. In doing so, it can prepare graduates for meaningful engagement in a complex and interconnected world.

1 Introduction: What's in a name? The semantic puzzle

The meaning of *competencies* and *skills* in engineering education has long been a subject of debate. Terms such as *competence*, *competency*, *skills*, *attributes*, and *capabilities* are often used interchangeably, yet they are not synonymous. Each term has distinct historical origins, theoretical foundations, and cultural connotations (Guerrero & De los Ríos, 2012; Le Deist & Winterton, 2005; Westera, 2001). Because these differences guide how we design learning outcomes, interpret accreditation expectations, and communicate expectations to students or employers, the terminology we use matters. Ambiguity can create misalignment between what is taught, what is assessed, and what students believe matters for their professional development (Passow & Passow, 2017; Suleman, 2018).

Across Europe, educational systems prioritise different traditions and values, which contributes to variation in how competencies are conceptualised and enacted. While the Bologna Process and the European Qualifications Framework (EQF) provide shared descriptors, countries interpret these in different ways (Europass, n.d.). In German-speaking contexts, *Kompetenz* is often associated with demonstrated performance in authentic situations (Glaesser, 2018), whereas Nordic traditions frame competencies more holistically, integrating knowledge, skills, and attitudes within broader pedagogical models (Crawley et al., 2014; Le Deist & Winterton, 2005). In the UK and Ireland, the discourse of graduate attributes and employability shapes how competencies are described, resulting in a more labour-market oriented vocabulary (Kaasa et al., 2014; Passow & Passow, 2017). These contrasts illustrate that competencies terminology is not neutral: it reflects underlying assumptions about what engineering education is for and what engineers should become. Understanding these differences helps you to make intentional decisions about defining, teaching, and assessing competencies in your own context. Clear terminology strengthens programme coherence, supports collaboration across teaching teams, and helps students articulate their abilities to diverse audiences.

This chapter examines competencies terminology from multiple perspectives. Section 2 traces its historical and conceptual evolution. Section 3 reviews political and policy frameworks shaping contemporary definitions. Section 4 discusses the broadening of competencies from technical to transferable dimensions. Section 5 analyses regional, linguistic, and cultural interpretations. Section 6 examines how competencies terminology is used within engineering education research. Section 7 synthesises these insights and reflects on why definitions matter for educational design and professional practice.

2 A historical and conceptual evolution

Understanding how the concept of competencies has evolved helps you make sense of today's diverse terminology. Although competency as a concept is now widely used across engineering education, its meaning is rooted in different academic traditions that developed over time. These origins continue to influence how competencies are framed in contemporary curricula and research.

Early theoretical work in psychology laid the foundation for the term. White (1959) introduced the notion of competence as an individual's ability to interact effectively with the environment, emphasising intrinsic motivation and adaptation. McClelland (1973) later argued that *competencies* were better predictors of occupational success than intelligence, shifting the focus from innate ability to observable performance in real contexts. These early definitions positioned competencies as something that can be demonstrated through behaviour rather than inferred from abstract measures of ability.

In vocational and professional education, competencies became associated with the ability to perform specific tasks to an expected standard (Eraut, 1994). This tradition, strongly shaped by industrial labour needs, emphasised observable skills, procedural knowledge, and measurable performance, often linked to workplace requirements. While this behaviourist orientation aligned with contemporary needs for efficiency and standardisation, it also contributed to what Westera (2001) later described as a "*confusion of tongues*," as different sectors and disciplines adopted the term in divergent ways.

In its early European form, engineering education emerged with a strongly utilitarian mission. France's *École Nationale des Ponts et Chaussées* (1747) was established to train civil engineers for large-scale infrastructural and urbanisation projects (Miller, 2013). In the United States, the *U.S. Military Academy at West Point* (1802) linked engineering education closely to military and nation-building priorities, preparing engineers for roles in the Army Corps of Engineers (Zelbo, 2023). During the World Wars, engineering expertise became a strategic asset, prompting critical reflections on the risks of producing technically skilled but ethically unreflective professionals; Adorno (1971) famously warned against education that cultivated technical compliance without moral agency. For much of the twentieth century, competencies meant technical mastery, a view reinforced during the Cold War and space race. These examples illustrate how conceptions of competencies have been historically shaped by the socio-political purposes engineering education was expected to serve.

By the late twentieth century, socio-economic and educational changes broadened the concept. Influenced by globalisation, technological change, and lifelong learning agendas, competencies came to include not only knowledge and skills but also attitudes, values, and behaviours (Barrick, 2017; Boyatzis, 1982; Kearns et al., 2016). This more holistic interpretation gained prominence in professional fields, where complex problem solving, ethical judgement, and collaboration became essential expectations for graduates.

Engineering education responded to these broader shifts. The rise of project-based and problem-based learning provided environments in which students could practise collaboration, communication, and reflective judgement alongside technical work (Boelt et al., 2022; Hadgraft & Kolmos, 2020). As engineering roles diversified, competencies expanded to encompass cognitive, interpersonal, and intrapersonal dimensions (Cruz et al., 2020; Male, 2010). Expectations for engineers to address

sustainability challenges, digital transformation, and sociotechnical complexity further reinforced this multidimensional understanding (Hadgraft & Kolmos, 2020; Jørgensen & Valderrama, 2016).

This historical layering explains why contemporary frameworks mix behavioural, cognitive, interpersonal, and ethical dimensions. These conceptual trajectories form the backdrop against which policy frameworks and accreditation logics have further institutionalised particular interpretations of competencies — an evolution explored in the next section.

3 Competencies in the political agendas

The conceptual evolution of competencies has increasingly intersected with political agendas and international quality assurance mechanisms. Over the past three decades, policy frameworks and accreditation systems have played a central role in institutionalising competencies, shaping how you are expected to formulate learning outcomes, design curricula, and align programmes with broader policy goals. These frameworks translate broad ideas about competencies into formal descriptors used across higher education systems.

A major turning point was the Bologna Process (1999), which aimed to harmonise degree structures across Europe and placed learning outcomes at the centre of transparency, mobility, and comparability. By requiring qualifications to be expressed in terms of what graduates should know and be able to do, Bologna brought competencies to the foreground of curriculum design (Bologna Declaration, 1999; Maffioli & Augusti, 2003). Building on this foundation, the EQF (Europass, n.d.) introduced a shared structure organised around *knowledge, skills, and competences*, offering a common reference point while still allowing national interpretations.

In engineering education specifically, these policy principles were operationalised through the EUR-ACE Framework Standards and Guidelines, administered by the European Network for Accreditation of Engineering Education (ENAE). EUR-ACE (2024) defines expected programme outcomes across technical, analytical, interpersonal, and ethical domains, including teamwork, communication, sustainability awareness, and project management — thus influencing how you should describe, teach, practice and assess competencies within your programme.

At the global level, the International Engineering Alliance (IEA) coordinates multilateral agreements — such as the Washington, Sydney, and Dublin Accords — which have contributed to a common vocabulary for describing what engineering graduates should know and be able to do across different education systems. These accords support international comparability of engineering programmes, enabling graduates from accredited programmes to be recognised across participating jurisdictions (IEA, n.d.).

In the United States, ABET's shift in the late 1990s toward outcomes-based accreditation formalised competencies in terms of demonstrable learning outcomes, a movement that influenced global discussions about articulating graduate expectations (Shuman et al., 2005). In Europe, the EUR-ACE Framework — developed within the

Bologna and EQF context — was formulated to be compatible with the IEA Graduate Attributes, ensuring that the competencies language used in European engineering programmes aligns with internationally recognised outcome descriptions.

At roughly the same time as ABET's reform, the CDIO Initiative (Conceive-Design-Implement-Operate), originating at Massachusetts Institute of Technology (MIT) and co-developed with Swedish partner universities, introduced a new engineering curriculum model integrating technical foundations with personal, interpersonal, and professional competencies. CDIO embedded transferable competencies such as teamwork, ethics, communication, and design skills within authentic project-based learning approaches (Crawley et al., 2014). Its influence expanded globally, reinforcing the growing international movement toward competencies-oriented engineering education.

Complementary initiatives outside engineering have further shaped the broader discourse on competencies.

- The OECD's Definition and Selection of Competencies project (DeSeCo), initiated in the late 1990s, introduced influential definitions of *key competencies* for participation in the knowledge society, contributing to the adoption of transversal competencies language in European policy contexts (Rychen, 2019).
- ESCO (European Skills, Competencies, Qualifications and Occupations) (2022), launched in 2010, developed multilingual classifications of skills and competencies to link educational descriptors to labour-market needs, and its taxonomy continues to inform discussions on terminology.
- UNICEF (2019, 2022) highlighted transferable competencies like critical thinking, adaptability, and collaboration, which support civic, social, and professional engagement.
- UNESCO (2021) emphasised core competencies for sustainable development, including systems thinking, anticipatory reasoning, and ethical awareness.

Although these frameworks differ in purpose, scale, and vocabulary, they collectively signal a broadening of competency expectations — from technical proficiency alone to behaviour, judgement, collaboration, and societal responsibility — and influence the broader policy environment in which engineering education operates.

Despite their value, policy-driven frameworks are not without criticism. First, competencies risk being reduced to checklists if adopted superficially, encouraging compliance rather than genuine curricular integration and neglecting their developmental and contextual nature (Cruz et al., 2020). Second, overlapping frameworks can create terminological redundancy or conceptual ambiguity if their conceptual underpinnings are not made explicit (Guerrero & De los Ríos, 2012). Third, an overemphasis on employability risks narrowing the mission of engineering education, sidelining ethical and societal responsibilities (van der Vleuten, 2015). For you, this means you need to engage with frameworks critically to ensure that competencies serve educational purposes rather than bureaucratic ones.

In sum, political frameworks, international agreements, and engineering-specific initiatives have transformed competencies from a loosely defined idea into a formal organising principle of engineering education across Europe and beyond. This institutionalisation has broadened competency expectations from technical expertise to include interpersonal, ethical, and sustainability-related dimensions. The next section explores this widening scope and its implications for teaching and assessment.

4 From technical to transferable: broadening the scope

Engineering education has long been associated with strong foundations in mathematics, physics, and disciplinary knowledge. Historically, competencies were primarily defined in technical terms, emphasising analytical proficiency and the ability to apply scientific principles to well-structured engineering problems. However, as discussed in earlier sections, the scope of competencies has broadened significantly in recent decades, reflecting changes in engineering practice, labour market expectations, and societal priorities.

Several factors have driven this shift. A key driver has been the increasing complexity of engineering work. Globalisation has intensified the need for engineers who can collaborate across cultural, disciplinary, and organisational boundaries, while rapid technological development and digitalisation demand continual learning and adaptation (Hadgraft & Kolmos, 2020; Leslie, 2016; Van Maele et al., 2013). Sustainability challenges call for systems thinking, ethical reasoning, and the capacity to work with multiple stakeholders on value-laden problems (UNESCO, 2021). Together, these developments have reframed engineering competencies as a multidimensional construct that extends beyond technical expertise to include interpersonal, intrapersonal, and societal dimensions.

Importantly, the distinction between technical and transferable competencies is not absolute. Many competencies, such as problem-solving or design thinking, combine disciplinary knowledge with interpersonal, intrapersonal, and contextual dimensions (Hadgraft & Kolmos, 2020; Male, 2010; Passow & Passow, 2017; UNESCO, 2021), making them inseparable from professional practice.

This broadening has significant implications for pedagogy. Technical competencies are typically domain-specific and traditionally assessed through examinations, laboratory work, or design tasks that test students' ability to apply theoretical knowledge. Transferable competencies, by contrast, are cross-cutting and require integrative, experiential, and often collaborative learning approaches. Consequently, traditional lecture-based instruction is increasingly supplemented or replaced by active, student-centred learning approaches such as project-based learning (PjBL), problem-based learning (PBL), and work-integrated learning (WIL). PBL, for example, enables students to collaborate, manage time and resources, communicate with stakeholders, and reflect on their learning — mirroring real-world engineering practice (Boelt et al., 2022).

Despite this progress, challenges persist. Terminological ambiguity continues to exist, with terms such as *generic*, *soft*, *non-technical*, *21st-century*, *professional*, and

transversal competencies often used interchangeably despite subtle differences (Kearns et al., 2016; Knipprath & De Ryck, 2013; UNICEF, 2019). This ambiguity can complicate communication between educators and between educators and students. Another risk is treating transferable competencies as add-ons or secondary elements rather than integral to engineering curricula. Meaningful integration requires explicit alignment of learning outcomes, teaching strategies, and assessment, ensuring that transferable competencies are developed progressively and intentionally rather than incidentally (Boelt et al., 2022; Cruz et al., 2020; Shuman et al., 2005).

Finally, the growing prominence of transferable competencies raises fundamental questions about the purpose of engineering education. Should its primary aim be to ensure employability, equipping graduates with the competencies demanded by contemporary labour markets? Or should programmes aim to cultivate reflective professionals capable of contributing to sustainable and just societies? This tension echoes broader debates in education (Biesta, 2009). These goals are not mutually exclusive but require careful balancing to avoid narrow interpretations of competencies that prioritise short-term labour-market needs at the expense of broader professional and societal responsibilities. A competency-based approach can support this balance when framed critically and reflexively, moving beyond checklists to embrace the dynamic, developmental, and context-dependent nature of engineering competencies (Craps et al., 2021; Cruz et al., 2020). This handbook provides you with a series of concrete examples on how you can do this.

5 Regional, linguistic, and cultural contexts: a patchwork of terms

Competency terminology does not travel neutrally across regions. Different linguistic traditions, educational histories, and cultural expectations shape how competencies are understood, enacted, and valued (Kaasa et al., 2014; LeDeist & Winterton, 2005). As engineering programmes increasingly operate in international and intercultural environments, understanding these variations becomes essential for curriculum designers and educators supporting diverse student cohorts.

A first source of variation lies in language itself. Multilingual classification systems such as DISCO (European Dictionary of Skills and Competencies) illustrate how several European languages use a single term to refer to *competence*, *competency*, and *skill*, making distinctions less explicit than in English (DISCO, 2022; Guerrero & De los Ríos, 2012). This linguistic overlap means that similar words may refer to broader or narrower constructs depending on local usage.

To illustrate, we briefly explore the terminology in the authors' regions. In French, *compétence* can refer to both jurisdictional authority (e.g., legal competence) and personal or professional ability. However, a distinction exists between *compétence* and *capacité*, reflecting deeper institutional traditions: the former is linked to measurable ability, the latter to potential — differences that influence how transferable and technical competencies are formulated in curricula (Keating, 2004). In German, there is a clearer distinction between *Kompetenz* (integrated competency) and *Fähigkeit* (ability or skill). In Danish, *kompetence* is framed more holistically,

integrating knowledge, skills, and attitudes within collaborative and student-centred pedagogies such as CDIO (Crawley et al., 2014), and is contrasted with *dygtighed* or *færdighed* (concrete skills). In Dutch, *bekwaamheid* (a professionally recognised qualification, e.g., a teaching certification) differs from *competentie* (broader educational capability) and *vaardigheid* (concrete skill).

These linguistic subtleties reflect deeper assumptions about learning and professional formation. A competency framed as *habitual* in one linguistic tradition may imply automatic or routine behaviour, whereas in another it may signal adaptive expertise developed through reflective practice. Such nuances influence how educators frame expectations and how students understand what is being assessed.

Cultural norms also shape how competencies are enacted. For example, communication competency varies across cultural settings. In German contexts, engineering communication values precision and explicitness, whereas English-speaking traditions emphasise audience adaptation and clarity of structure, and some Southern European styles place greater emphasis on relational and contextual meaning (Joo, 2024; Kaasa et al., 2014). East Asian teamwork may foreground group harmony and hierarchical sensitivity, with indirect communication strategies and a strong emphasis on cohesion (Hofstede et al., 2010).

As a consequence, a student who appears assertive in one context may be judged as confrontational in another. Similarly, a student who communicates indirectly may be perceived as diplomatic in one culture but insufficiently clear in another. These differences complicate assessment, as criteria developed in one cultural framework may not fully capture competency as enacted elsewhere. Example 1 further illustrates two different ways of looking at teamwork and how these cultural variation show in assessment rubrics.

Example 1. Cultural variation in teamwork and its implications for assessment

Engineering teamwork is universal, but how teamwork is enacted and assessed varies across cultural regions (Hofstede et al., 2010). The following two examples show that understanding these differences helps educators recognise why students may demonstrate competencies differently, and why rubrics need cultural sensitivity.

Nordic countries: teamwork as egalitarian collaboration

- *Nordic cultures place a strong emphasis on equality, low hierarchy, consensus building, and shared responsibility, shaping teamwork as a flat, co-constructed process.*
- *A typical rubric emphasises balanced participation, co-decision making, rotating leadership, consensus orientation.*

German-speaking countries: teamwork as a structured coordination

- *German workplaces value direct, clear, structured communication with strong expectations for punctuality, planning, and accountability — traits that translate into a structured framework.*

- *A typical rubric emphasises role clarity, reliability, advancing planning, task ownership, and explicit documentation.*

Recognising these cultural patterns supports fairer, more informed competency assessment, especially in international classrooms.

A consequence is that graduates trained in one system may struggle to communicate their competencies effectively in another or may find their abilities interpreted differently by employers across cultures (Passow & Passow, 2017). However, at the same time, diversity can be an asset. Exposure to different interpretations of competencies helps students cultivate intercultural adaptability and reflexivity — qualities increasingly valuable in global engineering practice.

Beyond Europe, global variations add further layers. In the United States and Australia, competency is often framed through measurable student outcomes, reflecting accountability cultures in higher education (Passow & Passow, 2017). Beyond the framing and perception of competencies, different competencies are prioritised across other regions. For example, engineering programmes in parts of Latin America foreground social justice and community engagement, while some East Asian systems prioritise technological competitiveness and coordinated industrial advancement, influencing expectations for innovation-oriented and systems-thinking competencies (UNESCO, 2021).

Taken together, these examples show that competencies are both multidimensional and culturally situated. Definitions may appear aligned on paper, yet their meanings, expectations, and behavioural expressions vary widely across linguistic and cultural contexts. This underlines the situated nature of competencies: they cannot be fully divorced from the cultural rules that shape professional interaction. Understanding these variations supports more inclusive curriculum design, more nuanced assessment, and more effective communication with international students and partners. It also prepares graduates to navigate the culturally diverse settings in which contemporary engineering practice unfolds.

6 Terminology in engineering education research

Engineering education research has played a central role in shaping how competencies are understood, investigated, and applied in curriculum and assessment practices. While previous sections traced the historical, political, and regional origins of competency terminology, this section explains how research traditions, methods, and assessment studies shape what we learn about competencies in engineering education. The field has become increasingly interdisciplinary, and over the last decade converges on a view of competencies as integrative, situated, and sociotechnically aligned with the realities of contemporary engineering work.

6.1 Interdisciplinary origins and their impact on terminology

Competency research in engineering education draws on multiple disciplinary traditions, and each brings its own assumptions, constructs, and terminology.

Psychology and learning sciences conceptualised competencies as behavioural effectiveness, with measurable individual attributes (e.g., White's (1959) motivation-based competence and McClelland's (1973) testing "*competence rather than intelligence*"). This tradition informs many measurement instruments and behavioural rubrics used in engineering education.

Vocational and pedagogical traditions introduced holistic and practice-based interpretations, emphasising the integration of knowledge, skills, and values in authentic contexts (Eraut, 1994). The 'competency movement' in HR and management focused on job performance and observable standards with workplace validity (Boyatzis, 1982). More recent policy studies broadened the notion of competencies as societal contributions and key competencies for life and work (e.g., OECD's DeSeCo), a lens that later influenced many engineering education framings of transversal or transferable competencies. The notion of competencies as sociotechnical constructs stems from sociology and science & technology studies.

Because these traditions co-exist, the literature uses the partially overlapping terms *competence*, *competency*, *capability*, *readiness*, and *dispositions*, which often carry different meanings across studies, depending on the theoretical lens adopted (Kearns et al., 2016). For example, *capability* is often used in educational contexts to emphasise potential and adaptability, while *readiness* is more common in workforce development literature. The influence of these external disciplines is evident in the way competencies are framed. Some strands present competencies as static lists of attributes, while others view them as dynamic, context-dependent constructs that evolve over time and reflect complex professional judgement (Craps et al., 2021; Cruz et al., 2020; Male, 2010).

These conceptual differences or underlying assumptions are often not fully acknowledged in engineering education research.

6.2 Competency domains in engineering education research

A scan of leading journals in the field, such as the Journal of Engineering Education (JEE), the European Journal of Engineering Education (EJEE), IEEE Transactions on Education (ToE), and the Australasian Journal of Engineering Education (AJEE), shows recurring domains rather than a single definition. Researchers examine competencies in relation to programme aims and study contexts and pedagogy, which explains the diversity but also the fragmentation. For an overview of measurement and definition issues, see the systematic review by Cruz et al., (2020).

A first prominent domain focuses on *generic or transferable competencies*— skills that are considered essential across all engineering disciplines and professional contexts. Male (2010, p.41), for example, defines generic engineering competencies as "*knowledge, skills, attitudes and dispositions that are important across all areas of engineering, and facilitate the success of engineers as individuals and their contributions as engineers to a well-functioning society*". These include communication, teamwork, ethical reasoning, and lifelong learning competencies. Literature increasingly recommends embedding these competencies in disciplinary

learning rather than treating them as add-ons (e.g., through design reviews, project reports, or client presentations).

Second, *employability-oriented competencies* are often framed in terms of the transition from education to work. Studies in this area emphasise problem solving, teamwork, communication, and critical thinking as key attributes valued by employers (EbrahimNejad, 2017; Fleming et al., 2024). Passow and Passow (2017) conducted a systematic review of employer surveys and identified problem solving as one of the most frequently cited competencies, particularly when it is integrated with technical knowledge. However, Lutz and Paretti (2021) caution that employability is context-dependent, shaped by organisational cultures and job roles. They argue that it is difficult to define a universal set of employability competencies, and that educational programmes must be responsive to local and sector-specific needs. In line with this, Craps et al. (2021) found that competencies vary according to the job role.

Finally, research also expanded toward *sustainability-related* and *sociotechnical competencies*. Research following frameworks like UNESCO (2021) highlights systems thinking, anticipatory and normative reasoning, stakeholder engagement, and ethical judgement as emerging core expectations. Studies now investigate how to weave these into mainstream engineering modules (e.g., thermodynamics, mechanics) rather than isolating them in electives (Desha et al., 2019; Gonçalves Quelhas et al., 2019). These emerging domains reflect shifting societal expectations of engineers and highlight the increasing need for sociotechnical competencies.

Across these thematic domains, research indicates that competency development benefits from student-centred, practice-based environments, such as problem- and project-based learning, design-implement experiences, and work-integrated learning, because they supply the authentic contexts where integration, judgement, and collaboration are visible (Boelt et al., 2022).

6.3 Methodological challenges in competency research

Terminological inconsistency creates substantial methodological challenges for research. Operationalisation varies widely. A systematic review of competency methods in engineering education found significant inconsistencies in how frameworks were selected, justified, and applied (Cruz et al., 2020). Many studies fail to explain how competency constructs were derived or to justify their alignment with theoretical assumptions, resulting in weak construct specification (Carthy et al., 2019; Suleman, 2018).

A further challenge lies in the overreliance on self-report measures, which are easy to administer but often poor proxies for enacted competency, and restrict comparability across contexts (Carthy et al., 2019). A meta-analysis of professional-skills studies found that many instruments collapse complex constructs into single Likert-scale items (e.g., 'rate your teamwork skills from 1 to 5'), limiting interpretability and making cross-study comparison difficult (Carthy et al., 2019). Such oversimplification reflects deeper divergences between behavioural, holistic, and developmental understandings of competencies and results in inconsistent measurement choices across the literature.

These issues indicate the need for greater conceptual transparency, stronger theoretical justification for operationalisation choices, and multi-method designs that acknowledge the integrative and situated nature of competencies highlighted in contemporary scholarship (Cruz et al., 2020). This call provides the foundation for more coherent, context-sensitive assessment approaches.

6.4 Assessing competencies: persistent challenges and emerging directions

Assessing competencies remains a central difficulty in engineering education research because the complexity and situated nature of competencies are hard to capture with standardised tools. As noted in the previous section, inconsistencies in conceptualisation translate directly into measurement problems. Many studies rely on self-report surveys or analytic rubrics, which offer scalability but often fail to represent how competencies are enacted in authentic settings (Carthy et al., 2019; Suleman, 2018). Simplified indicators, such as single-item ratings of teamwork or communication, are common but restrict comparability across contexts (Lutz & Paretti, 2021). Systematic reviews likewise show that many assessment instruments lack explicit theoretical grounding or justification for operationalisation choices (Cruz et al., 2020).

Qualitative approaches provide richer insight into competencies as situated performance. Interviews, reflective journals, and ethnographic observations reveal how students make decisions, negotiate roles, integrate prior knowledge, and respond to uncertainty. Yet these methods have limitations: they are labour-intensive, difficult to scale, and challenging to standardise without compromising depth (Suleman, 2018). The contrast between scalable but reductive quantitative tools and insightful but resource-intensive qualitative approaches highlights a central methodological tension in competency assessment.

Recent research therefore explores hybrid or innovative approaches. Situational judgement tests (SJTs), for instance, probe professional and sociotechnical reasoning more authentically, though concerns remain regarding contextual validity and transferability (Carthy et al., 2022). Performance-based assessments, such as design reviews or integrated sociotechnical cases, offer higher ecological validity but face challenges of assessor training, reliability, and feasibility at a larger scale.

Across studies, the shared conclusion is that competency assessment requires a multi-method, developmental approach, integrating behavioural evidence, reflective judgement, and performance in authentic tasks (Cruz et al., 2020). Moving forward calls for greater reflexivity, transparency, and interdisciplinary dialogue to build a more coherent and inclusive understanding of competencies and what it means to be a competent engineer in a complex and changing world (Phillips et al., 2024).

7 Why definitions matter: critical reflection and future directions

Competencies are not fixed or universal constructs. Across this chapter, competencies emerged as a historically layered, politically situated, culturally embedded, and research-contested concept. This multiplicity is not a weakness, but a reflection of the

many different purposes which competencies serve in engineering education – from curriculum design and assessment to shaping the identities of future engineers and supporting educational and professional mobility. This section synthesises these insights and considers how emerging developments may further shape competency terminology in the years ahead.

7.1 *Critical reflection: navigating persistent tensions*

A first tension concerns the gap between *formal definitions* and *situated meaning*. While broadly used frameworks, such as the EQF, EUR-ACE, the IEA Graduate Attributes, and ABET's outcomes, provide stability, they inevitably condense complex professional behaviour into simplified descriptors. In practice, however, competencies are enacted through local pedagogical traditions, disciplinary expectations, and cultural norms. You therefore work with definitions that aim for comparability across systems and simultaneously must be interpreted within specific institutional and cultural settings. This duality is not a flaw of competencies frameworks but a reminder that translation is always required.

This tension highlights the importance of making interpretative choices explicit rather than assuming shared understanding, as summarised below.

Uniform definitions of competencies may be neither possible nor desirable. Instead, engineering education benefits from making differences explicit. Transparency supports:

- Clearer communication within teaching teams,
- More consistent assessment practices,
- Reduced confusion for students,
- Improved collaboration across programmes and institutions,
- Greater mobility and mutual understanding across Europe.

Plural interpretations of competencies allow programmes to reflect their missions while still aligning with broader European and global expectations.

A second tension lies in the *risk of misalignment* between what is stated, what is taught, and what is assessed (Kovacs et al., 2023). If competencies are phrased in broad terms, but operationalised through narrow indicators, students receive mixed messages about what matters. Conversely, if competencies are invoked rhetorically without being intentionally embedded in teaching activities, they become disconnected from practice. For instance, if teamwork is valued, but not explicitly taught or assessed, students may not develop the skills needed to collaborate effectively in professional settings. Misalignment does not stem from a lack of frameworks but from insufficient clarity about how local interpretations relate to programme outcomes. Clear internal articulation helps bridge these gaps.

Related to this is the *risk of reductionism*. Competencies can be flattened into checklists when pressure towards accountability outweighs attention to development. For instance, when '*communication*' is reduced to the ability to write reports, this fails to capture the developmental and cultural richness of communicative practice. While

structured rubrics support reliability, they cannot fully capture how judgement, uncertainty, or interdisciplinary negotiation unfold in authentic engineering work (Heywood, 2016). Recognising this limitation encourages you to embrace a more balanced approach: using structured indicators where useful, while also allowing space for professional reasoning and contextual decision making.

A third tension concerns *developmental trajectories*. Early-stage demonstrations of competencies differ significantly from the expectations placed on graduating students (Cruz et al., 2020). For example, a first-year engineering student's problem solving typically involves structured tasks with clear parameters, whereas a master student may be expected to work with ill-structured, ambiguous problems that demand creativity, judgement, and autonomy. However, definitions often present them as static end-states. Without recognising gradual progression or levels of proficiency — from novice to expert — assessment risks either underestimating early learning or overestimating what can reasonably be expected. Making developmental expectations explicit at module and programme levels helps students understand how competencies grow and where they are positioned within that trajectory.

Finally, the chapter has shown that *cultural* and *contextual variation* remains unavoidable. Engineering programmes reflect national and cultural traditions regarding what it means to be an engineer (Lucena et al., 2008). Competency terms that appear aligned across countries often differ in connotation, scope, or behavioural expression (Kaasa et al., 2014; Van Maele et al., 2013). Rather than attempting to erase these differences, productive practice requires acknowledging them and making local meanings explicit. This does not undermine international comparability; instead, it strengthens it by clarifying the assumptions that inform your definitions.

Together, these tensions highlight that competencies should not be treated as a finished product to be consumed, but as a language of design. Their usefulness depends on how well you make visible the interpretive choices behind your definitions and how consistently you translate these into teaching, assessment, and programme communication. Example 2 presents concrete strategies that support educators in putting these ideas into practice.

Example 2. From definitions to practice: strategies for aligning competency development

- Make definitions explicit. *Clearly articulate how you understand key competencies such as teamwork, communication, or problem solving.*
- Align outcomes, teaching, and assessment. *Ensure that what you value in your programme is intentionally taught and meaningfully assessed.*
- Use authentic contexts. *Provide opportunities (e.g., PBL, design projects, reflective assignments) for students to enact competencies in realistic settings.*
- Address cultural variation openly. *Discuss with students how competencies can look different across cultural or disciplinary contexts.*
- Encourage reflection. *Support students in developing awareness of how their competencies evolve over time and across situations.*

7.2 Looking ahead: evolving expectations for competencies

The conceptual tensions above become even more pronounced as engineering practice evolves. As an example of this evolution, we discuss two current developments that stand to reshape how you may define and assess competencies in the coming decade.

The first concerns the deepening integration of *artificial intelligence* and *data-driven tools* in engineering work (Schleiss et al., 2022). As computational processes become partially automated, the emphasis shifts from executing analytical procedures to interrogating algorithmic results, validating data sources, and making informed judgements under uncertainty. These shifts invite you to reconsider how analytical, ethical, and communication competencies are defined. The expectation that engineers can explain, question, and justify decisions informed by AI — rather than simply produce correct outputs — suggests that epistemic and value-laden aspects of competencies will become more prominent.

The second development is the gradual adoption of *modular learning* pathways and *micro-credentials* (Ironsi & Ironsi, 2025). These initiatives promise flexibility but challenge programme coherence: competencies that were once embedded across multi-year curricula must now be recognisable in smaller units of learning. For you, this evolution underscores the need for transparent level descriptors, clear evidence requirements, and cross-referencing with qualification frameworks such as the EQF, so that modular recognition does not dilute the meaning of competencies.

These shifts do not replace traditional competency domains; rather, they expose dimensions that may previously have been implicit, such as algorithmic responsibility, systems thinking, or stakeholder negotiation, and bring them more centrally into definitions and assessment.

7.3 Towards reflexivity and shared awareness

Definitions matter because they influence what is taught, what is assessed, and how students understand their own development. Although competency terminology will continue to evolve, especially under the influence of AI and modular learning, its value lies in how explicitly and coherently you choose to use it. By approaching competencies with conceptual clarity, recognising their contextual nature, and designing learning environments that reflect its integrative character, you can navigate the inherent tensions productively and prepare graduates for a profession that increasingly demands both technical sophistication and sociotechnical judgement.

8 Conclusions

This chapter has examined the contested concepts of competencies and skills in engineering education, with a particular emphasis on Europe, situated in a global perspective. It traced the historical and conceptual evolution of competencies, examined the shift from technical to transferable competencies, and analysed their expression across regional, cultural, and research contexts.

Three insights stand out. First, terminological diversity — across languages, cultures, and research traditions — makes it impossible to arrive at a single, universally valid definition of competencies. Second, developmental trajectories remind us that competencies evolve over time and across roles, meaning that assessment must take progression and context into account. Third, cultural variation highlights that competencies such as communication, initiative, or leadership are expressed differently in different societies, requiring adaptability and intercultural sensitivity from graduates.

The challenge for European engineering education is therefore not to eliminate diversity but to engage with it constructively. Harmonisation efforts such as the Bologna Process and EQF remain valuable, but they cannot and should not erase longstanding differences. Instead, the goal should be to cultivate shared awareness: transparency about definitions, reflexivity about applications, and openness to plurality.

By adopting this stance, Europe can model a forward-looking approach to engineering education that values diversity as a source of strength. In doing so, it can prepare engineering graduates not only for professional mobility within Europe but also for meaningful engagement in a complex, interconnected world.

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AI statement

During the preparation of this work, the authors used Microsoft Copilot to check for spelling and grammar mistakes and improve coherence in text structure. After using this tool, the authors reviewed, edited and made the content their own as needed and take full responsibility for the content of the publication.

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1.3

Competency Frameworks of Use to Engineering Educators

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The competencies engineering students require are changing at a rapid pace due to evolving industry, societal, and technological demands. This has resulted in educators seeking guidance from, and often being overwhelmed by, the fragmented world of competency frameworks, which differ widely in scope, level of detail, and intended purpose. To address this challenge, we begin by contextualising this chapter by asking who would benefit most from reading it, before clarifying the distinction between taxonomies and competency frameworks. We then present three questions that will be used to guide discussion of several contemporary frameworks: what the framework's primary goal is, the areas for which it provides guidance, and how actionable it is. We apply these questions to the diverse frameworks of EntreComp, DigComp, GreenComp, EUR-ACE, CDIO, and UK-SPEC. We believe that our selection of frameworks and subsequent discussions serve as a strong starting point for engineering educators seeking to navigate this landscape with greater confidence.

1 Who would benefit from reading this chapter?

This chapter is written for practitioners in engineering education who are seeking orientation in the complex landscape of competency frameworks. The primary audience comprises lecturers, programme coordinators, deans, curriculum designers, and teaching and learning support staff working at undergraduate and postgraduate level. Engineering students are an indirect audience. While they are not directly addressed, the frameworks discussed shape the curricula, learning activities and assessments they experience. Throughout this chapter, we have used *competencies* instead of *skills* or similar terminology. When referring to this term, we link our understanding to Chapter 1.2 and the definition by Passow (2012, p. 97): “*competencies are defined as the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skilfully (i.e., to make sound decisions and take effective action) in complex and uncertain situations such as professional work, civic engagement, and personal life*”. Thus, we understand competencies not merely as knowledge or skills, but as dynamic, learnable dispositions that manifest in purposeful and effective performance within complex contexts.

The development of competencies is a lifelong and context-sensitive process, closely tied to performance and evaluative judgement (Rychen & Salganik, 2000; Woollacott, 2009). Against this background, engineering educators are facing increasing pressure to align curricula with rapidly evolving societal, technological, and professional demands. These include sustainability, digitalisation, global collaboration, and artificial intelligence (Hadgraft & Kolmos, 2020; SEFI, 2025).

At the same time, the landscape of competency frameworks is broad and fragmented, with a growing number of overlapping or even conflicting frameworks claiming to define what engineering graduates should be able to do. As noted by Richter and Kjellgren (2025), the abundance of such frameworks can be overwhelming, especially regarding the variety in quality, focus, and practical applicability. Many frameworks provide only vague definitions or lack practical indicators, which makes their application in curricula or teaching strategies challenging. This abundance and vagueness can confuse those at the beginning of their exploration.

Too much detail can result in a framework being inapplicable in another context, whereas too little detail can leave individual educators to make highly subjective decisions. Crossin et al. (2023) emphasise that while competency frameworks provide valuable guidance, their often non-prescriptive nature complicates the task of mapping frameworks onto the varied realities of engineering practice. As Richter and Kjellgren (2025) observe, subjectivity arises when indicators lack specificity in a commonly faced challenge.

This chapter responds to these challenges by presenting a structured and accessible selection of frameworks. It aims to help you gain an initial overview without requiring deep prior knowledge of each. Our focus is not on prescribing a single solution, but rather on offering a guided entry point by providing a comparative and annotated set of frameworks that is indicative of current priorities in engineering education, primarily

across Europe. This approach should help educators navigate the field more confidently and help inform decision making when selecting or adapting frameworks for specific institutional or programmatic contexts.

2 Asking the right questions: How to choose a fit-for-purpose resource

Given the large number of competency-related resources available today, engineering educators can justifiably feel uncertain about how to interpret and use them. Many documents are labelled as frameworks, inventories, or similar terms, yet they differ substantially in scope, level of detail, and intended use.

This section aims to address this challenge by first addressing the often-misunderstood distinction between taxonomies and frameworks, and second by offering a set of guiding questions to support fit-for-purpose selection.

Taxonomies primarily classify and organise competencies or skills, while competency frameworks go beyond classification by providing structure, progression, and in some cases guidance for educational action (Child & Shaw, 2020; Wozniak, 2024). Taxonomies and competency frameworks can therefore be considered to form the two ends of a spectrum of utility. It can be helpful for engineering educators to position a given resource along this spectrum.

Examining how a resource is organised — for example, whether it presents simple lists or detailed outcome descriptions — can help to indicate its intended purpose and practical usefulness. At the same time, it is important to recognise that neither taxonomies nor competency frameworks can ever be complete or absolute. Both reflect competencies deemed relevant within a specific time and place, while being applied in different contexts.

In this sense, competency-related resources should be understood as aiming to support more informed professional judgement — being *good enough* to guide decision making, rather than offering definitive solutions. This contextual limitation is further reinforced by the rapidity of societal and technological change. For example, research on skills conducted prior to the widespread impact of GenAI or the COVID-19 pandemic may already be outdated. Similarly, the sources informing skills recommendations have evolved over time.

To support educators in evaluating both taxonomies and competency frameworks, this chapter proposes three guiding questions (see Table 1.3.1). These questions are intentionally generic and can be applied across different types of resources:

1. What is the resource's primary goal (e.g., to define, assess, or develop competencies and skills)?
2. In which areas does it provide guidance (e.g., curriculum or module design, assessment, professional development)?
3. How actionable is it (e.g., does it include performance indicators, progression levels, or sample rubrics)?

An example of a resource whose utility aligns more closely with a taxonomy than with a competency framework is the World Economic Forum's 21st-century skills (2015). It comprises 16 skills grouped into three categories: foundational literacies (core skills), competencies (skills for solving challenges), and character qualities (skills for navigating change). If we analyse the skills taxonomy of the World Economic Forum (WEF) using our three questions, a clear profile emerges:

- Its primary goal is to define and classify competencies and skills, rather than to specify how they should be assessed or developed.
- The guidance it provides is primarily for high-level curriculum considerations, helping educators identify which skills to include in a programme.
- Its actionability is limited; as a descriptive list of topics, it typically lacks the concrete performance indicators or progression levels needed to design specific teaching activities or assessment rubrics.

This is largely continued in the WEF's 2025 Future of Jobs Report (World Economic Forum, 2025), though the guidance provided is primarily industry related.

In addition, many widely used resources in engineering education, such as EUR-ACE or ABET, function as accreditation standards rather than taxonomies, while UK Standard for Professional Engineering Competence and Commitment (UK-SPEC) also operates as a regulatory standard for professional registration. They share the prescriptive qualities of competency frameworks, providing clear pathways to specific educational outcomes, but carry additional regulatory force in defining what accredited programmes or registrants must demonstrate.

An example of such a framework is the European Entrepreneurship Competence Framework (EntreComp), which offers a set of scaffolding elements that educators can draw on when designing for entrepreneurial competency development (Bacigalupo et al., 2016). EntreComp organises 15 competencies into a hierarchy of three categories, namely Ideas and Opportunities, Resources, and Into Action, and supplements these with a progression model of eight proficiency levels articulated through 442 learning outcomes. Unlike a simple taxonomy, these elements give educators concrete material to work with when sequencing learning, defining outcomes, and designing assessment.

Accordingly, a competency framework yields different answers to our guiding questions than a taxonomy does:

- Its primary goal goes beyond just defining competencies and skills to actively guiding how they can be developed and assessed.
- It therefore provides guidance in more detailed areas of curriculum design and student professional development, showing how competencies can be progressed over time.
- This makes a competency framework typically more actionable, as it typically includes the specific performance indicators and progression levels that educators need to design meaningful learning activities and assessment rubrics.

Now that we have a clear method for identifying and understanding different resources, the following section provides an overview of selected competency frameworks used in engineering education today.

3 A selection of diverse frameworks for engineering education practitioners

Having provided background context regarding frameworks and the questions to be asked when working with them, we present below the frameworks we have selected to expand on in this chapter. Our aim is to furnish the above discussion with concrete examples, while also linking you to other sections of this handbook to dive deeper.

The selection was guided by four considerations: (1) relevance to current engineering education challenges (e.g., sustainability, digitalisation, employability), (2) diversity of framework types (e.g., geographical scope, accreditation standards, engineering education approaches), (3) variation in intended application level (e.g. curriculum, programme, professional, or module level), and (4) their influence within engineering education practice. The guiding questions introduced in Section 2 are then used to analyse and compare these selected examples.

The six frameworks discussed in Table 1.3.1 serve different functions, and it is useful to distinguish three broad categories before examining each in turn. The first comprises European Union-level competence frameworks, namely EntreComp (Bacigalupo et al., 2016), DigComp (Vuorikari et al., 2022), and GreenComp (Bianchi et al., 2022), all developed by the European Commission's Joint Research Centre as non-prescriptive reference models intended to provide a shared conceptual vocabulary for lifelong learning across sectors and educational levels. Their function is orientational: they describe what competent action in a given domain looks like, but they neither prescribe curricula nor certify programmes.

The second category consists of regulatory and accreditation standards, namely UK-SPEC (Engineering Council, 2020) and EUR-ACE (ENAAEE, 2021). Both define minimum outcomes that engineering graduates or registrants must demonstrate and carry formal consequences, though they differ in mechanism: EUR-ACE accredits programmes directly, whereas UK-SPEC sets the standard for professional registration and shapes education indirectly through the AHEP accreditation standard.

The third category is community-driven engineering education frameworks, of which the CDIO syllabus (Crawley et al., 2011) is the principal example in this chapter. These emerge from networks of engineering educators rather than from regulatory or policy bodies, and their function is to support curriculum and module design through detailed, practice-oriented educational goals.

These distinctions matter because each type answers a different question for the educator: EU frameworks help articulate which competencies to develop, while regulatory and accreditation standards specify what a programme or registrant must demonstrate.

Table 1.3.1: Overview of selected competency frameworks with guiding questions.

	<i>What is the framework's primary goal?</i>	<i>In which areas does it provide guidance?</i>	<i>How actionable is it?</i>
EntreComp	Foster a value-creation mindset (Bacigalupo et al., 2016)	Programme design; competency assessment; learning activity design	Model with eight proficiency levels to help learning and assessment design
DigComp	Develop digital competencies and skills (Vuorikari et al., 2022)	Labour market skill requirements; education and training curricula	List of 21 skills with examples of knowledge, skills, and attitudes
GreenComp	Develop sustainability competencies across Europe (Bianchi et al., 2022)	Education at all levels; learner development	List of 12 competencies across four areas and 40 learning outcomes
EUR-ACE	Define minimum outcomes and quality standards for engineering programmes	Programme design; accreditation; quality assurance	Eight learning areas with clear cycle-level expectations
CDIO Syllabus	Define and structure practice-oriented engineering competencies to guide curriculum development	Curriculum and module design; systematic curriculum development; alignment with engineering practice	A structure with multiple levels of detail for curriculum development and outcome definition
UK-SPEC	Define and assess the standards for professional engineering and technician registration in the UK	Professional assessment and registration; professional and ethical standards; curriculum and module design	Five performance indicators, progressional levels and examples of evidence

These six frameworks were developed with different audiences in mind. Recognising this matters when translating them into engineering education contexts. EntreComp, DigComp, and GreenComp are not engineering-specific, which means engineering educators using them must do additional work to translate generic competence descriptors into discipline-relevant learning outcomes. EUR-ACE and the CDIO Syllabus were developed specifically for engineering programmes and educators, so the translation effort is smaller, although institutional adaptation is still required. UK-SPEC sits apart: it was written for individual engineers seeking professional registration, and its influence on engineering education is indirect, mediated through the AHEP accreditation standard.

The citizen-oriented frameworks offer transversal orientation that requires substantial adaptation, the engineering-specific frameworks offer closer-to-ready scaffolding, and the regulatory standards set the required outcome for programmes. These six frameworks will be discussed in more detail below.

3.1 *EntreComp*

The European Entrepreneurship Competence Framework, EntreComp, was published by the European Commission in 2016. It was developed by the EC's Joint Research Centre (JRC) feeding into *A New Skills Agenda for Europe* (European Commission, 2016), a communication from the European Commission to address the skills gap detected in the EU, which was considered a threat to stability and social cohesion. The agenda lays out three strategic pillars. The first — *"Improving the quality and relevance of skills formation"* — includes the action area *"Building resilience: key competences and higher, more complex skills"*, which places a special focus on promoting entrepreneurial mindsets. EntreComp has since been reaffirmed by the Union of Skills strategy, as it includes an explicit undertaking for higher education to integrate entrepreneurship training across all disciplines (European Commission, 2025).

Introduced in Section 2 as one of the most comprehensive models of its type, the European Entrepreneurship Competence Framework, EntreComp defines 15 entrepreneurial competencies across three areas and a progression model of eight proficiency levels defined by 442 learning outcomes (Bacigalupo et al., 2016). On first impression, it appears highly actionable for practitioners, with progressive learning outcomes helping educators better design learning activities and assessment rubrics. However, its complexity presents challenges to its use. The EntreComp areas and competencies are:

- *Area 1.* Ideas and opportunities, consisting of spotting opportunities, creativity, vision, valuing ideas, and ethical and sustainable thinking.
- *Area 2.* Resources, consisting of self-awareness and self-efficacy, motivation and perseverance, mobilising resources, financial and economic literacy, and mobilising others.

- *Area 3. Into action*, consisting of taking the initiative, planning and management, coping with uncertainty, ambiguity and risk, and working with others.

EntreComp illustrates how a competency framework can provide engineering educators with ready-made scaffolding, in the form of competence areas, progression levels, and learning outcomes, that can be adapted into competency development scripts for specific curricular or modular contexts.

Like many competency frameworks, EntreComp uses a specific lexicon that may not align with common usage. Its definition of entrepreneurship is: *"[T]he capacity to act upon opportunities and ideas to create value for others. The value created can be social, cultural, or financial, recognising social value, cultural capital, as well as money"* (McCallum et al., 2018). This is markedly broader than the dictionary sense of someone *"who owns and manages a business, bearing the financial risks of the enterprise"* (Oxford English Dictionary, n.d.). This gap matters for practitioners: a quick reading of the framework's headline diagrams, interpreted through prior assumptions, can obscure its intent and how its competencies are defined and measured. Recognising EntreComp's expansive view of entrepreneurship, from business creator to transferable competency, also has practical consequences. In an engineering education setting, it implies that entrepreneurship should not be taught as a niche subject outsourced to business schools but integrated into mainstream engineering modules. Therefore, one major criticism of EntreComp for engineering educators is its size and complexity.

Additionally, practitioners might find curriculum design and assessment through separate learning outcomes for each competency and/or area a flawed approach. This is supported by a study conducted by Joensuu-Salo et al. (2022), who questioned the theoretical validity of the framework's proposed multidimensional structure of three areas of entrepreneurial competency. They found a high correlation between assessments targeted at different areas of the framework. For example, a student who scores well in one area will likely score well in all others.

EntreComp's aim of fostering a value-creating mindset is ambitious, but the framework does not itself develop these competencies in learners. Used alongside this handbook, practitioners can draw selectively on its elements to design learning activities and assessments, while remaining alert to its complexity and to the assumptions embedded in its lexicon.

3.2 DigComp

The impact of digital technologies and how we respond to them is significant (Draghi, 2024; European Commission, 2026). DigComp, the European Digital Competence Framework for Citizens, is a research-driven framework developed by the European Union to provide a common understanding of digital competency to aid in the development of digital literacy (Vuorikari et al., 2022).

The primary function of DigComp is to provide a standardised language to describe digital skills and competencies, creating a standardised reference point for diverse

stakeholders (Ikanos, n.d.; Vuorikari et al., 2022). This aids policymakers to formulate strategies, educators to design curricula, employers to define job requirements, and citizens to self-assess their skills. Although DigComp was developed for citizens rather than engineering professionals, its relevance to engineering education is twofold.

First, contemporary engineering graduates operate as digital citizens as well as technical practitioners: they are expected to communicate responsibly online, evaluate digital information critically, safeguard data, and engage with emerging technologies such as artificial intelligence in their interactions with colleagues, clients, and the public. Digital citizenship in this sense functions as a transversal graduate attribute that complements, rather than competes with, discipline-specific technical competencies.

Second, DigComp provides a common vocabulary that engineering programmes can use to articulate the digital dimensions of generic graduate outcomes (communication, lifelong learning, professional responsibility) which already appear in accreditation standards such as EUR-ACE and UK-SPEC. For engineering educators, then, DigComp is useful less as a substitute for discipline-specific digital skills frameworks and more as an orientation tool for the transversal, citizenship-oriented dimensions of digital literacy that engineering graduates carry into professional practice.

DigComp is structured around five core competence areas: information and data literacy; communication and collaboration; digital content creation; safety; and problem solving. These are broken down further into 21 specific skills and competencies (Vuorikari et al., 2022, p. 4). For assessment purposes, DigComp introduces a progression model of eight proficiency levels for each competency, grouped into four main stages, namely Foundation, Intermediate, Advanced, and Highly Specialised. This progression maps to increasing levels of cognitive complexity and learner autonomy, from requiring guidance for simple tasks (Level 1) to creating new ideas and resolving complex problems (Level 8) (Vuorikari et al., 2022). In addition to the levels, throughout the DigComp publications, examples of knowledge, skills, and attitudes are provided.

The framework has been regularly updated to keep up with technological development. The latest version, DigComp 2.2, was released in 2022 to address emerging technologies like artificial intelligence and new societal trends such as remote work (Vuorikari et al., 2022). There are also multiple spin-offs, such as the Digital Competence Framework for Educators (DigCompEdu) which focuses specifically on the pedagogical use of digital technologies (Redecker, 2017). This specialised framework has spurred a rich ecosystem of teacher training programmes and self-reflection tools, such as SELFIEforTEACHERS, which helps educators at pre-tertiary level assess their own digital skills (Redecker, 2017), promoting a pedagogical shift from teaching isolated 'computer skills' to embedding digital competency development across the entire curriculum. An additional example is the CRISS project, which developed a competency-based assessment model where students apply digital skills to solve problems within their regular subjects (Guitert et al., 2021). A notable use of DigComp in the engineering field comes from the Visual Literacy in Engineering

Education (VLEE) project (Rózewski et al., 2021), in which visual literacy skills were aligned with DigComp (Martín Erro et al., 2022).

A large amount of literature has been written on the framework and its derived assessment instruments. These include studies that have used quantitative methods to confirm the framework's five-area structure in diverse cultural and educational settings (Abubakari et al., 2025; Gómez-Trigueros et al., 2025), as well as practical accounts where researchers have used DigComp to assess the competency levels of various populations, such as university students and educators (Saltos-Rivas et al., 2022). Studies often find that while basic skills are common, proficiency in more complex areas like *Digital Problem Solving* and *Digital Content Creation* is lacking (Abubakari et al., 2025).

Beyond academia, DigComp is a useful tool for policy and employment, as it serves as a key reference for national and regional governments in designing digital skills strategies that align with EU-wide goals (Kluzer & Pujol Priego, 2018). For the labour market, the framework provides a standard for defining digital skill requirements in job roles, assessing candidates, and identifying training needs (Kluzer et al., 2020). This practical application is supported by an ecosystem of assessment and certification, ranging from free self-assessment tools that let individuals benchmark themselves against the standard to formal certifications offering verifiable credentials for the labour market, such as the ICDL, which has aligned its modules with DigComp (ICDL Foundation, n.d.).

3.3 GreenComp

The European Sustainability Competence Framework, GreenComp, is one of the policy actions in the European Green Deal, which aims to develop sustainability competencies within the European Union and its citizens. Within GreenComp, sustainability competencies are understood as empowering “*learners to embody sustainability values, and embrace complex systems, in order to take or request action that restores and maintains ecosystem health and enhances justice, generating visions for sustainable futures*” (Bianchi et al., 2022, p. 12).

GreenComp identifies four areas — embodying sustainability values; embracing complexity in sustainability; envisioning sustainable futures; and acting for sustainability — and 12 competencies to support the development of knowledge, skills, and attitudes that prioritise care and respect for the environment.

Like other European Commission competency frameworks, such as EntreComp and DigComp, GreenComp is designed as a non-prescriptive reference model. Its role is to provide a shared conceptual foundation that can be applied flexibly across a wide range of lifelong learning contexts and purposes (Bianchi et al., 2022). Although GreenComp was not developed specifically for engineering education and addresses learners across all educational levels, it is included here because sustainability has become a central expectation for engineering graduates and curricula (e.g., Royal Academy of Engineering, 2025). For engineering educators, GreenComp can therefore

serve as an orientation framework for identifying sustainability-related competencies, while requiring translation into engineering-specific learning outcomes and contexts.

Unlike EntreComp and DigComp, GreenComp does not provide proficiency levels or assessment guidance that can be applied directly in educational and training programmes. It nonetheless remains a competency framework rather than a taxonomy: it organises sustainability competencies into four interrelated areas with embedded progression logic, articulates the underpinning knowledge, skills, and attitudes, and was designed to guide curriculum and programme development across lifelong learning contexts (Bianchi et al., 2022). Where proficiency-level scaffolding is required for educational application, derivative works fill the gap. The most developed example is the OpenPass4Climate project (Martín-Ramos et al., 2025), a university consortium funded by the EU, which produced a set of 40 learning outcomes distributed across GreenComp's four areas and 12 competencies, translating its abstract concepts into actionable and measurable form.

Below is an excerpt of the learning outcomes proposed for competence Area 1 (sustainability values) and competence 1.1 (valuing sustainability):

1. Critique sustainability arguments, policies, and actions by analysing their underlying values and principles, including cultural and generational differences.
2. Negotiate solutions that reach a consensus aligned with specific sustainability principles while respecting diverse stakeholder perspectives.
3. Design and implement a personal action plan, applying concrete sustainability principles to daily choices.
4. Analyse how consumption drivers impact resource demand and environmental and social sustainability.

The 40 learning outcomes are comprehensive enough to adapt to all levels in education, whether in a formal or informal context. They have been designed to encourage behavioural change and emotional engagement as well as knowledge and understanding. This promotes learner transformation rather than focusing on skills attainment, as is the case with EntreComp and DigComp.

3.4 EUR-ACE framework standards and guidelines

The EUR-ACE label, awarded by the European Network for Accreditation of Engineering Education (ENAE), is a Europe-wide quality mark for engineering degree programmes at both bachelor and master levels (see Chapter 1.4 for further information). Compliant with the European Qualification Framework (EQF), ENAE defines a set of programme outcomes and quality standards that describe the knowledge, skills, and abilities engineering graduates from an accredited degree programme are expected to demonstrate. Europe's EUR-ACE system, like America's ABET, abides by international accreditation agreements, e.g., the Washington Accord, which is discussed in more detail in Chapter 1.4.

The mission of ENAE "is to serve the public and society through the promotion and advancement of engineering education in Europe and abroad. ENAE aims at building

a pan-European framework for the accreditation of engineering education programmes, to enhance the quality of engineering graduates, to facilitate the mobility of professional engineers and to promote quality and innovation in engineering education” (ENAE, 2021, p. 3). Since 2006, over 3,800 engineering programmes at more than 680 universities in 30 countries (in Europe and beyond) have received the EUR-ACE label, showing reliability and adaptability to different national contexts.

The EUR-ACE Framework Standards and Guidelines (EAFSG) include eight learning areas, each with specified learning outcomes that apply to bachelor (first-degree cycle, FCD) and master, (second-degree cycle, FCD): knowledge and understanding, engineering analysis, engineering design, investigations, engineering practice, making judgements, communication and teamworking, and lifelong learning. Both cycles address the same core competencies, but the expected depth and autonomy differ.

Bachelor's programmes focus on building a solid foundation of scientific and technical knowledge alongside practical problem solving skills, while master programmes expect graduates to work more independently, manage complex projects, and tackle open-ended or unpredictable engineering challenges. Importantly, the programme outcomes present the *minimum threshold* for engineering degrees. Table 1.3.2 shows an excerpt regarding the learning areas Communication and Team-working and Lifelong Learning, (ENAE, 2021 p. 11).

Table 1.3.2: EUR-ACE Framework Standards and Guidelines for communication and teamworking in EUR-ACE (adapted from ENAE, 2021)

<i>The learning process should enable bachelor degree graduates to demonstrate:</i>	<i>The learning process should enable master degree graduates to demonstrate:</i>
Ability to effectively communicate information, ideas, problems and solutions with the engineering community and society at large;	Ability to use diverse methods to communicate clearly and unambiguously their conclusions, and the knowledge and rationale underpinning these, to specialist and non-specialist audiences in national and international contexts;
Ability to function effectively in a national and international context, as an individual and as a member of a team, and to cooperate effectively with engineers and non-engineers.	Ability to function effectively in national and international contexts, as a member or leader of a team that may be composed of different disciplines and levels, and that may use virtual communication tools.

These outcomes serve as a reference for practitioners both for developing engineering programmes and for evaluating these during accreditation, across all engineering disciplines and profiles (ENAE, 2021). It is important to note that the standards

describe the programme outcomes that accredited programmes must achieve, but they do not prescribe *how* these outcomes are achieved, as they do not represent didactic guides. Thus, higher education institutions remain free to develop programmes with their own focus and identity, including innovative formats, and to set their own admission requirements.

Beyond graduate competencies, the EUR-ACE framework also sets requirements for programme design and quality assurance. Accredited programmes must demonstrate that their intended outcomes are clearly formulated, aligned with stakeholder and labour-market needs, and supported by appropriate teaching methods, staffing, resources, and internal evaluation processes. In doing so, the label not only signals technical quality but also confirms that programmes are systematically organised to produce capable, adaptable engineers.

3.5 CDIO Syllabus

The CDIO (Conceive–Design–Implement–Operate) initiative is a global educational framework for engineering education with the goal of preparing graduates for real-world engineering practice. Originating in the early 2000s, the initiative was driven by the question of which knowledge, skills, and attitudes engineering students need in order to be prepared for professional practice, in response to a perceived gap between education and real-world demands (Crawley et al., 2011; Crawley et al., 2014).

CDIO builds on the premise that the lifecycle of products, processes, or systems defines the context of engineering education, as these stages represent the authentic contribution of engineers to society (Crawley et al., 2011). This vision was summarized in the following statement: “*Graduating engineers should be able to conceive-design-implement-operate complex value-added engineering systems in a modern team-based environment*” (Crawley et al., 2011, p. 3).

Besides the CDIO Standards, which provide an overview of principles for implementing CDIO, the key outcome of the initiative was the CDIO Syllabus, which is a structured reference framework of topics indicating desirable competencies of engineering graduates. Instead of providing another list of graduate attributes, the syllabus provides detailed and actionable educational goals to support curriculum and module development (Crawley et al., 2011; Edström & Kolmos 2014).

The CDIO syllabus has been shown to align well with national and international accreditation requirements such as ABET, EUR-ACE, and UK-SPEC (Crawley et al., 2011; Malmqvist 2009). Comparative analyses show that graduate attributes across Washington Accord organisations are also reflected in the CDIO Syllabus (Paul et al., 2015). However, since accreditation standards evolve continuously, maintaining an up-to-date alignment remains an ongoing task (Malmqvist et al., 2022).

The syllabus is designed to be comprehensive yet non-prescriptive (Crawley et al., 2011; Malmqvist et al., 2022). It serves as a flexible reference to support curriculum design, benchmarking and accreditation, while requiring adaptation to specific institutional contexts and stakeholder needs (Malmqvist et al., 2022).

The CDIO Syllabus 3.0, the latest version, is structured into five main areas (Malmqvist et al., 2022):

1. *Fundamental Knowledge and Reasoning*. Covers core scientific and engineering knowledge, now expanded to include social sciences and humanities, acknowledging the broader context of engineering work.
2. *Personal and Professional Skills and Attributes*. Encompasses problem solving, experimentation, systems thinking, ethical reasoning, lifelong learning, and adaptability, among others.
3. *Interpersonal Skills*. Focuses on teamwork, collaboration, and communication.
4. *Conceive–Design–Implement–Operate (CDIO) Skills*. The ability to conceive, design, implement, and operate products, processes, and systems within enterprise and societal contexts.
5. *Expansion*. A new section addressing competencies such as leadership, entrepreneurship, and research, which are essential for some but not all graduates.

Each area is broken down into subcategories and multiple levels of detail, allowing educators to engage at different depths, depending on whether they focus on programme-level design or individual modules. This flexible structure aims to avoid overwhelming new users while still supporting curriculum mapping when needed.

Currently, the CDIO initiative is a worldwide community, yet its participation and research output are strongly concentrated in Europe, particularly in Nordic countries (Malmqvist et al. 2019; O'Connor et al., 2023). A systematic review of CDIO knowledge library publications (2010–2020) by O'Connor et al. (2023) shows that most work focuses on implementation, with comparatively few evidence-based studies. The authors call for more evidence-based research and cross-institutional collaboration to strengthen CDIO's long-term impact. Regarding impact, Pick et al. (2021) examined alumni who graduated before and after CDIO implementation. Their study found perceived improvements in teamwork, communication and design skills, while also noting that further development is needed in other competencies. Implementing CDIO at the programme level requires significant effort, coordination among stakeholders and often involves curricular restructuring (González et al., 2019).

Taken together, the CDIO Syllabus serves both as an orientation tool and a design resource. For institutions beginning to engage with competency-based engineering education, it offers a coherent, structured overview of the full landscape of skills 21st-century engineers require.

3.6 UK-SPEC

In the United Kingdom, public, employers, and government trust in the engineering profession is formally upheld by a key regulatory standard: *The Standard for Professional Engineering Competence and Commitment* (UK-SPEC) (Engineering Council, 2020). Published by the Engineering Council (EC), which operates under a Royal Charter conferring it legal jurisdiction, the standard proposes a benchmark of competency against which professional engineers are formally assessed. The

Engineering Council maintains a national register of these engineers and technicians and is active in international agreements such as the Washington Accord to ensure that UK engineers are recognised globally.

The process for attaining professional registration involves a peer review consisting of a portfolio of evidence and interviews. This is undertaken by Professional Engineering Institutions (PEIs) licensed by the Engineering Council, such as the Institution of Mechanical Engineers (IMechE) and the Institution of Engineering and Technology (IET). Successful professional registration entitles engineers to use one of three protected titles that signify their level of competency and responsibility: the first tier consists of Engineering Technicians (EngTech), the middle tier consists of Incorporated Engineers (IEng), and the highest tier is the Chartered Engineer (CEng).

The UK-SPEC framework itself is defined by five broad competency areas that applicants must demonstrate. These are: Knowledge and Understanding; Design, Development and Solving Engineering Problems; Responsibility, Management and Leadership; Communication and Interpersonal Skills, and Professional Commitment. Each registration level requires the applicant to meet specific sub-competencies under each area.

The influence of UK-SPEC includes this handbook's structure. The book's three themes, Responsibility, Project Management and Leadership; Communication and Interpersonal Skills; and Professional Commitment and Lifelong Learning, are developed from the Chartered Engineer Standard listed in the UK-SPEC.

As a regulatory standard, a key distinction of UK-SPEC is that it is not expected to directly shape learning processes, in contrast to educational frameworks such as CDIO. Primarily, it serves as a mechanism via which engineers demonstrate that they are worthy of the trust that society places in the engineering profession to regulate itself.

Despite this apparent distinction, UK-SPEC in fact strongly influences and shapes engineering education via the Accreditation of Higher Education Programmes (AHEP) standard (currently AHEP4) (Engineering Council, 2020), which is published by the EC in tandem with UK-SPEC. This translates the competency requirements defined in UK-SPEC into a set of criteria that engineering programmes should meet, akin to EUR-ACE accreditation standards. For more information on accreditation, see Chapter 1.4.

Viewed in a wider context, as observed by Gonzalez (2025), UK-SPEC exemplifies a regulatory philosophy rooted in the UK's historical traditions of standards and external accountability. From this perspective, UK-SPEC can be envisioned as an example of how a national regulatory framework might shape its country's engineering education and distinguishes it from other countries.

4 Summary

This chapter offers engineering education practitioners an entry point into the vast landscape of competency frameworks. We began by distinguishing taxonomies, which classify and organise competencies, from competency frameworks, which add

structure, progression, and guidance for educational action, positioning the two as ends of a spectrum of utility rather than discrete categories.

Three guiding questions were proposed to help you evaluate any given resource: what its primary goal is, the areas in which it provides guidance, and how actionable it is. These questions were then applied to six contemporary frameworks of relevance to engineering education in Europe and beyond: EntreComp, DigComp, GreenComp, EUR-ACE, the CDIO Syllabus, and UK-SPEC. The selected examples therefore represent different purposes and levels of application, ranging from broad European competency frameworks to accreditation standards and engineering-specific educational approaches. The chapter does not prescribe a single solution but instead emphasises that frameworks should be understood as orientation tools whose effective use is frequently enhanced through derivative works that provide contextual adaptation, critical reflection on purpose, and alignment with institutional needs.

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Quality by Design: The Role of Accreditation in Transferable Competencies and Skills Development

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Over the past two decades, engineering accreditation has increasingly adopted an outcomes-based model centred on the development and demonstration of graduate competencies and skills. This chapter examines how local accreditation systems and international frameworks support the formation of competent engineers by focusing on what graduates should be able to do rather than prescribing detailed curricular inputs. The chapter explores the structure and function of contemporary accreditation frameworks, including the relationship between global principles and local professional standards. Particular attention is given to how programme teams translate accreditation requirements into curriculum design, learning outcomes, and assessment strategies that provide credible evidence of competence attainment. Approaches to curriculum mapping and assessment design that support successful accreditation are discussed, alongside examples of how engineering education research has informed the evolution of accreditation standards. A case study illustrates a practical approach to curriculum design that aligns programme learning outcomes, assessment practices, and accreditation expectations. The chapter concludes with recommendations for practitioners involved in programme leadership, accreditation preparation, and curriculum development. Collectively, these perspectives highlight how accreditation can function not merely as a quality assurance mechanism, but as a constructive framework supporting the development of capable, adaptable, and professionally prepared engineers.

1 Introduction

Engineering education has long relied on external accreditation, that is, *“the process by which a (non-)governmental or private body evaluates the quality of a higher education institution as a whole or of a specific educational programme to formally recognise it as having met certain pre-determined minimal criteria or standards. The result of this process is usually the awarding of a status of recognition, and sometimes of a license to operate within a time-limited period”* (Vlăsceanu, 2007, p. 25). Accreditation provides an independent, internationally recognisable assurance that an engineering programme truly prepares graduates for professional practice — not only in technical fundamentals, but also in professional judgement, ethics, and responsibility for real-world impacts — thus strengthening employer and public trust, improving graduate recognition and mobility, and differentiating graduates in contexts where the title ‘engineer’ may be used loosely. At the same time, accreditation acts as a structured driver of continuous improvement by bringing external peer and professional scrutiny, encouraging closer engagement with industry and society’s needs, and ensuring that programmes communicate clearly and transparently about what students achieve and how quality is sustained over time.

In the nineteenth century, national engineering institutions emerged, gaining responsibility for the accreditation of engineering programmes and eventually forged contemporary multilateral accords such as the Washington Accord (WA) and the EUR-ACE Framework Standards and Guidelines (EAFSG), often referred simply as EUR-ACE standards or framework. These frameworks and accords, which ensure globally aligned accreditation standards, have progressively converged on a shared understanding of what it means to be prepared for engineering practice. Over time, a system has developed that allows educational providers to benchmark their programmes against expected norms, these being informed by the underpinning science, relevant technologies, and societal concerns. Today, outcome-based descriptors of knowledge, skills and behaviours supply a common vocabulary for educators and regulators worldwide, enabling the mutual recognition of degrees and the mobility of graduates.

Accreditation, which is an objective evaluation and approval of third-level engineering programmes to ensure they meet professional standards, is more than a compliance exercise; it is fundamentally a curriculum design challenge. Programme teams must demonstrate that learning activities, resources and assessments are constructively aligned with the targeted outcomes, and that students attain them. This demands evidence-informed approaches to module sequencing, integrative projects, and authentic assessment, coupled with robust quality assurance loops that capture feedback from students, industry partners and (in some regions) external examinersⁱ, union representatives, or similar stakeholders who provide externality and sharing of good practice to maintain and develop standards. Institutional leaders, for their part, position accreditation as a strategic enhancer of educational quality, embedding it within broader improvement cycles rather than treating it as a periodic audit (Guerra et al., 2017). Though it is understood that it is a considerable undertaking, there are

arguments for professionalizing the approach to the teaching of engineering, and institutional accreditation of degrees coupled to individual professional registration (as is required in some countries).

The landscape is being reshaped by powerful forces: digital transformation, interdisciplinary practice, sustainability imperatives, the widening participation agenda, and the pedagogical implications of generative and other forms of artificial intelligence. These trends are recalibrating the competencies expected of engineering graduates and the evidence accreditors look for, compelling universities to rethink not only programme content but also how learning is facilitated and verified.

Against this dynamic backdrop, the chapter that follows provides you, the practicing academic, with a guide to aligning programme design with contemporary accreditation needs. After quickly tracing the historical evolution of systems, the chapter dissects the logic of major international frameworks and translates these into high-level criteria. A case study illustrates how institutions have integrated these accreditation requirements into the education and assessment of their students, while a forward-looking analysis identifies persistent challenges before proposing coordinated, competency-focused solutions. Together, these insights aim to transform the perception of accreditation from a bureaucratic obligation into what it is meant to be: an evidence-based continuous improvement activity, and a driver of educational excellence to be embraced by all engineering educators.

2 Accreditation systems

2.1 History of accreditation framework

The first engineering institutions, professional bodies, and trade unions were established in the nineteenth century to advocate for the advancement of the profession and the development of its members, with the earliest examples appearing in the UK (1818), Ireland (1835), and the USA (1852). These are here referred to as Professional Engineering Institutions (PEIs). Some examples include the Institution of Engineers of Ireland (Engineers Ireland), Institution of Mechanical Engineers (IMechE) in the UK, and the Institute of Electrical and Electronic Engineers (IEEE) in the USA. Throughout the twentieth century, these professional bodies expanded their functions to include the regulation of the profession, through registration and professional licensure, and accreditation systems to ensure the quality of engineering programmes, with the first - ABET - being founded in the United States in 1932 (IEA, 2015).

By 1989, six professional bodies had found sufficient common ground in their accreditation systems to found the WA, a multilateral agreement between Australia, Canada, Ireland, New Zealand, the United Kingdom, and the United States, that recognised the substantial equivalence of engineering qualifications attained in each signatory's jurisdiction. The WA as of 2025 has 25 full signatories and six provisional signatories, making it the largest mutual recognition agreement currently in operation in the world (IEA, 2015).

In 2006, the European Network for the Accreditation of Engineering Education (ENAE) was established by 14 associations concerned with engineering education, with the main goal of building confidence in accreditation systems for engineering degree programmes in Europe. ENAE stemmed from the European Standing Observatory for the Engineering Profession and Education (ESOPE), which was founded in 2000 by five professional bodies from Germany, Italy, France, the United Kingdom, and Portugal (ENAE, 2022a). The first ENAE general assembly took place in March 2006, with the implementation of the EUR-ACE system of accreditation following shortly afterward in 2007. The EUR-ACE label is a European Quality Label authorised by ENAE to PEIs who accredit engineering programmes. Initially developed to provide mutual recognition of engineering qualifications and first-degree cycle (FCD), often bachelor degree, and second-degree cycle (SCD), often master degree in Europe, the number of professional bodies and agencies authorised to award the label has grown substantially since 2007 to 23, reaching jurisdictions across three continents (ENAE, 2022b).

In 2007, in response to several accords and agreements being created globally for the recognition of engineering qualifications from technicians, technologists and professional engineers, the International Engineering Alliance (IEA) was formed and a secretariat established to manage them (IEA, 2015).

The growth of these organisations did not come without challenges, as the IEA and ENAE remain to this day separate entities with different philosophies. However, many strides toward cooperation have been made, with the publication of the ENAE IEA Best Practices in Accreditation of engineering programmes in April 2015.

2.2 Learning outcomes, programme outcomes, and graduate attributes

Now that the history of accreditation frameworks has been sketched, some clarity can be added to the picture by defining learning outcomes, which link university programmes, national accreditation standards and international accreditation frameworks. While the definitions of competencies and skills have been predefined for the purposes of this handbook, it becomes important to talk in terms of outcomes when discussing what PEIs expect graduates to be able to do at the end of their studies. Broadly speaking, these outcome frameworks, which have been developed based on the same outcomes-based education (OBE) theory (Spady, 1994), may be achieved in various ways, which overlap somewhat, and which are used in different ways in different countries.

Learning outcomes form the basis on which national qualifications frameworks are built and are increasingly influential in defining and writing of qualifications and curricula as well as the orientation of teaching and assessment (Winterton et al., 2006). Learning outcomes are statements of what a learner knows, understands, and is able to do on completion of a learning process. The achievement of learning outcomes must be assessed through procedures based on clear and transparent criteria. Learning outcomes are attributed to individual educational components and to programmes as a whole. They are also used in European and national qualifications

frameworks to describe the level of the individual qualification (European Commission, 2015).

Programme outcomes (POs), which can be categorised in a similar manner to competencies and skills (both technical and transferable) are the discrete, observable outcomes expected of graduates upon completion of an engineering programme. They are written at a higher level than learning outcomes and refer to principles or goals for an engineering programme. For example, “*students will be able to demonstrate the ability to solve complex engineering problems relevant to their particular branch of engineering*”. Programme and learning outcomes should be aligned in order to achieve accreditation.

Graduate attributes, in the context of accreditation requirements, can be taken as synonymous with programme outcomes but may reflect more specific requirements. In some cases, for example in accreditation frameworks, they have more specific meaning, e.g., both the IEA and ENAEE have a set of definitions for graduate attributes which are intended to guide PEIs in developing POs within their respective accreditation requirements.

A critical point to note here is that individual PEIs have some latitude to interpret the graduate attributes within accreditation frameworks to formulate POs. This is often an action taken which reflects a more general, abstracted nature of (national or international) guidelines which apply to all engineers, regardless of the branch of engineering being practiced.

Locally, each signatory to the IEA accords or EUR-ACE is at liberty to define and emphasise the POs that are most relevant to their jurisdictional context, provided they can demonstrate alignment with the graduate attributes defined by these international frameworks. These local requirements will simply be termed accreditation requirements here, as they encompass a small number of input-resource requirements (quality assurance mechanisms, entry standards) as well as output requirements (POs). In recent years, several jurisdictions have taken a research-informed approach to the revision of accreditation requirements. In recent revisions to its outcomes, ABET has incorporated several refinements that align closely with empirical insights from Passow and Passow’s (2017) systematic literature review of engineering competencies. Notably, ABET’s expanded articulation of teamwork demonstrates a substantive shift from the earlier, passive formulation of ‘*functioning on multidisciplinary teams*’ toward a richer conception of collaborative practice. The revised outcome emphasizes leadership, goal formation, task planning, and the cultivation of inclusive environments. Similarly, ABET’s updated ethics outcome foregrounds informed judgement and explicit consideration of societal, environmental, and global impacts, partially addressing the critique by Passow and Passow (2017) that ethical responsibility in practice entails proactive stewardship rather than simple awareness. The integration of contextual constraints into both design and ethical reasoning further reflects their call to embed impact analysis within core engineering processes. While ABET’s criteria stop short of fully incorporating competencies such as initiative, creativity, and self-management — identified by Passow and Passow as

central to professional effectiveness — the revisions nonetheless represent a meaningful recalibration toward a more evidence-based understanding of engineering practice.

Over the past decade, the wider societal aspects of competencies and skills and their implementation in accreditation requirements have also garnered much attention. Examples include ethics, and sustainable practice. Martin (2020) and Homan (2020) both highlight the influential role PEIs play in shaping the engineering ethics curriculum and professional development of engineers. Homan also highlights how accreditation systems, as well as driving innovation in the curriculum, may also serve as a barrier to change, as many PEI accreditation processes lack one key stakeholder: the public; the end user of many engineering innovations.

While undoubtedly a range of approaches to teaching ethics can be observed in practice, Martin's findings suggest that ethics education is viewed as an add-on subject and is treated superficially in most curricula examined. To resolve this, a conceptual framework integrating ethics as a set of skills alongside ethics as concepts, knowledge, values, and attitudes was developed by Gwynne-Evans et al. (2021). Having applied their framework to the Engineering Council of South Africa's accreditation requirements, a new set of POs emerged that repositions ethics at the heart of engineering graduate attributes. This research is yet to garner the attention of an accreditation framework, such as the EUR-ACE or the IEA graduate attributes. It does, however, demonstrate how the social dimensions of engineering activities can be effectively embedded in the curriculum.

2.3 Accreditation frameworks

As intimated in the earlier sections, there are two prevalent accreditation frameworks with which PEIs who conduct accreditation can align their accreditation requirements to ensure the global mobility of graduate engineers educated within their jurisdiction. Table 1.4.1. provides a comparison of the POs from the ENAEE, EAFSG and the IEA Graduate Attributes, which set out the competence requirements that PEIs must evaluate as part of their accreditation criteria to be recognised under these respective accords. For comparison, the Engineers Ireland accreditation criteria have been included to illustrate how each set of POs has influenced the formation of a local set of accreditation requirements, as Ireland is a signatory to both the IEA Accords and EUR-ACE. Similarly, the Accreditation of Higher Education Programmes, Fourth Edition (AHEP4) standard applied in the UK is shown, indicating how the taxonomy alters by region for similar activities.

Both frameworks, as well as the Engineers Ireland and UK AHEP4 criteria, are in perfect harmony regarding the technical outcomes; all emphasising the importance of foundational knowledge of the engineering sciences, problem solving, analysis, and investigation. Differences emerge relating to transferable competencies and skills, but in the relative emphasis each receives within individual frameworks. Taking lifelong learning as an example, Table 1.4.2 shows that in the IEA Graduate Attributes and EAFSG, lifelong learning is the unitary object of analysis. By contrast, Engineers

Ireland adapted their accreditation requirements for lifelong learning to include teamwork. By contrast, AHEP4 stipulates these outcomes separately, as two of the 18 learning outcomes required.

Table 1.4.1: A comparison of the IEA graduate attributes, EUR-ACE programme outcomes, Engineers Ireland programme outcomes, and UK AHEP4 learning outcome groupings

<i>IEA graduate attributes (IEA, 2021)</i>	<i>EUR-ACE framework standards and guidelines (ENAE, 2022b)</i>	<i>Engineers Ireland programme outcomes (Engineers Ireland, 2021)</i>	<i>AHEP4 learning outcomes (ECUK, 2020)</i>
Engineering knowledge	Knowledge & understanding	Knowledge & understanding	Science and mathematics (commonly referred to as knowledge & understanding)
Problem analysis	Engineering analysis	Problem analysis	Engineering analysis
Investigation	Investigations	Investigation	
Design/development of solutions	Engineering design	Design	Design and innovation
Tool usage			
Engineer & the world	Making judgements	Professional & ethical responsibilities	Engineer & society
Ethics			
Lifelong learning	Lifelong learning	Teamwork & lifelong learning	Engineering practice
Individual & collaborative teamwork	Communication & teamworking		
Communication		Communication	
Project management & finance	Engineering practice	Engineering management	

Table 1.4.2: Comparison of definitions in competency statements on lifelong learning between IEA, EAFSG and signatory members Engineers Ireland and AHEP4 to both frameworks

<i>IEA (IEA, 2021)</i>	<i>ENAEF (ENAEF, 2022b)</i>	<i>Engineers Ireland (Engineers Ireland, 2021)</i>	<i>AHEP4 (ECUK, 2020)</i>
(1) Recognize the need for and have the preparation and ability for independent and lifelong learning,	(1) Ability to recognise the need for and to engage in independent lifelong learning.	(1) the ability to recognise and make use of the interactions between various engineering disciplines and other professions; the ability to work with a broad range of stakeholders in multidisciplinary settings;	(1) Function effectively as an individual and as a member or leader of a team.
(2) Recognize the need for and have the preparation and ability for adaptability to new and emerging technologies, and	(2) Ability to follow developments in science and technology.	(2) knowledge, understanding and active participation in diverse and inclusive teams;	(2) Evaluate effectiveness of own and team performance.
(3) Recognize the need for and have the preparation and ability for critical thinking in the broadest context of technological change.		(3) recognition of the need for, and the ability to plan and carry through, self-directed continuing professional development (CPD).	(3) Plan and record self-learning and development as the foundation for lifelong learning (CPD).

The tendency of individual PEIs to organise accreditation requirements in a way which aligns with social and cultural conventions is encouraged within accreditation frameworks, provided PEIs can demonstrate the substantial equivalence of their accreditation requirements to the relevant framework. It is noteworthy that strides have been made to better harmonize these frameworks and national accreditation requirements under a common set of competence statements. Van den Broeck et al. (2024) conducted a systematic literature review on lifelong learning competencies.

Through analysis of 65 papers, they identified and clustered 254 competencies relevant to lifelong learning to develop a six-competence lifelong learning framework for university students, unveiling fruitful ground for future revision of the definitions within accreditation frameworks and national accreditation requirements.

3 Strategies for curriculum design

Now that some sense of the interaction between accreditation frameworks and PEIs' jurisdictional accreditation requirements has been established, we explore the interaction between higher education institutions (HEIs) and the PEIs. To meet accreditation requirements, programmes taught at HEIs need to demonstrate that the POs defined by the PEIs are aligned with individual module learning outcomes. Here we see how developments to national and international standards impact local design and delivery of taught and assessed material. Accreditation acts as both driver for change in a curriculum and means to stabilize it: change driven by new, evolved stipulations from PEIs, and stabilization by the need to continuously demonstrate suitable adherence to a standard.

In regard to demonstrating the meeting of standards, multiple aspects are used, such as using a heatmap, cross-table, or other tool which highlights claims made about learning outcomes and their alignment to the accreditation requirements of the PEI in a particular jurisdiction. A sample heatmap is provided in Fig. 1.4.1. While we have seen many methodologies for the establishment of the scores attributed to each PO for a given module, an aggregated score based on the assessment of the learning outcomes for each module in terms of their contribution to a given PO is sufficient. The heatmap or cross-table serves as much as a reflective tool for you as the module lead as it does as an aid to the external assessors in directing their review of the evidence provided.

Module	ECTS	PEI Programme Outcomes			
		Teamwork	Communication	Ethics	Management
Module 1	3	4	3	5	2
Module 2	5	5	1	0	1
Module 3	10	0	0	5	4
Module 4	3	3	2	1	0
Module 5	5	5	5	5	1
Module 6	3	3	2	1	0

Figure 1.4.1: Sample heatmap for highlighting claims about the achievement of programme outcomes (Own Work by Carthy)

3.1 Mapping learning outcomes

Learning outcomes constitute the backbone of contemporary engineering curricula, articulating the knowledge, skills, and attitudes that graduates are expected to demonstrate (ENAE, 2022b). For engineering programmes, well-formulated outcomes perform three interconnected functions: (1) they align learning with rapidly evolving industry requirements and global standards such as the EAFSG and the IEA graduate attributes; (2) they assure transparency for students, employers, and accreditation bodies; and (3) they enable international mobility by providing a common language for recognition of competences and skills. The adoption of a shared terminology has enabled the preparation of the exemplar *Best Practice in Accreditation of Engineering Programmes* (ENAE & IEA, 2024). A holistic perspective demands that cognitive, social, and emotional dimensions be addressed in tandem. Technical proficiency in areas such as analytical modelling and problem solving must be complemented by teamwork, leadership, intercultural communication, and an ethical mindset, while emotional attributes — resilience, adaptability, and professional responsibility — support lifelong learning (Biggs & Tang, 2011). Recent revisions of the EUR-ACE and WA graduate attribute descriptors broaden the scope further by embedding sustainability, digitalisation and artificial intelligence literacy as cross-cutting themes, yet institutions still struggle to balance technical depth with wider professional capabilities, particularly in interdisciplinary or emergent fields where the target profile is itself fluid.

A major challenge faced by academic staff in the pursuit of mapping outcomes to accreditation requirements is in allocating responsibility for the mapping exercise. Here a *top-down* approach from the programme director (or programme director) can cause issues if the nuance of teaching in particular modules is not understood. Similarly, a *bottom-up* approach, where the responsible lecturers (or module leads) allocate learnings, can lead to unbalanced mapping, as the wider programme aims are not as visible. A *mixed-mode* approach works well, where the programme director asks responsible lecturers where modules are strong, then concert the efforts of the lecturers to allocate mapping where the evidence of robust demonstration is strongest. The mapping exercise may invoke a decision to be made on whether to create modules based on the learning need or to retrofit learning to existing modules. A reflection by the authors on the practices in the UK and Ireland highlights that several additional challenges have emerged and persist:

- Module topics based more on historical precedent than functional need. An example is the practice of resource teaching mathematics - where lecturers from the mathematics department teach engineering students fundamental mathematical content, which can be broad in scope with limited contextualisation within the physical science curriculum requirements of an engineering programme.
- To improve teaching efficiency there are drivers towards greater commonality in early parts of some degrees, with engineers from many disciplines taking the

same modules. This adds constraint due to differing PEI needs but affords opportunity to define activities that are truly core learning for all engineers.

- The professional experience of teaching staff, where staff teach on accredited programmes who themselves hold no professional registration, i.e., are not members of a PEI in a given jurisdiction, or who do not hold a pertinent teaching qualification, and so have not demonstrated understanding of the competencies required of an engineer. This is not to say that these educators are not competent, but that their competence has not been verified in an objective and systematic way in a manner consistent with the programme they are supporting.
- Striking the balance between the teaching of *up-to-date* skills, readily useful to service a narrow set of needs, with the development of confidence and competence in the application of underpinning principles to a wider set of problems; i.e., what Poser (1998) defines as “*the difference between know how and know why*”.
- Confusion of module learning outcomes and programme outcomes as defined within PEI accreditation requirements.

Considering these factors, a hybrid approach to mapping appears typical, where long-standing outcomes (for example associated with aspects of engineering science) may be easily accommodated in existing modules, but emergent standards may necessitate a new module. Key to successful mapping is a wide view of the programme needs, coupled with a narrower view of where and how claims are best demonstrated.

Other points to consider here include threshold and coverage: learning outcomes need to be demonstrated at a threshold (usually a passing grade) level only; the meeting of learning outcomes is not usually stipulated in terms of association with a specific module credit. Assessment needs to show learning needs are being met for a student getting a passing mark, not a high mark, and (usually) there is some latitude in the extent to which a particular learning outcome is demonstrated. A complicating factor here though is that if an assessment tests multiple competencies, there is a potential for a passing student to not adequately demonstrate all of these. As such, the careful design of assessments, including segregation into *must pass* elements, is important to ensure a robust and balanced coverage and a clear mapping onto PEI programme outcomes.

3.2 Authentic assessment to support the achievement of accreditation requirements

A significant challenge for HEIs is mapping transferable competencies and skills embedded within learning outcomes to accreditation requirements. Transferable skills such as communication, networking, creativity, and problem solving are increasingly prized by employers who recruit engineers for multi-disciplinary, client-facing roles — skills which are not always present at satisfactory levels in graduate engineers (Carthy et al., 2022). The role of authentic assessment, specifically how HEIs can leverage assessment to better align curricula with accreditation requirements, merits further discussion. Authentic assessment requires students to demonstrate competencies and

skills that realistically represent problems and situations likely to be encountered in their work life, or where students are required to complete tasks that have real-world applications. Practical examples include developing case studies, solving ill-structured problems, and participating in multidisciplinary projects. Authentic assessment remains one of the most reliable ways to measure transferable competencies and skills, because the approach mirrors the complexity of contemporary professional practice (Ajjawi et al., 2024).

It is a common quality assurance requirement that assessment demonstrates how individual students, not cohorts, have met learning outcomes. This should inform the design of any group assessment such that individuals are given the opportunity to demonstrate learning. Assessments including teamwork or communication often hinge on subjective judgement, so that reliability across assessors is hard to guarantee, and heavy workloads encourage summative tests at the expense of formative feedback. This can constrain the type of skill assessed in groupwork, but recent initiatives to mitigate these risks include institution-wide rubric design workshops, systematic peer and self-review cycles, and the deployment of AI-enhanced analytics capable of detecting rating anomalies in real time (Li et al., 2025).

It is important to remember that mapping itself is simply a tool to enable careful formation of the educational underpinning of future careers in engineering; the actual demonstration comes via assessment. Much of the challenge in mapping transferable competencies and skills to accreditation requirements stems from the need for authentic assessment strategies for the evaluation of transferable competencies and skills, which by contrast to traditional forms of assessment utilised in the evaluation of technical competencies, can be perceived as illusory. To support you in developing authentic assessment strategies for transferable competencies and skills, Part 3 of this handbook has been dedicated to assessment.

While PEIs will state that the most appropriate pedagogical method is the one that best achieves their accreditation requirements, in our experience student-centred approaches that embrace these alternative forms of assessment map much more precisely to the accreditation requirements relating to transferable competencies and skills than traditional forms of instruction and assessment.

3.3 *Advances in mapping methods*

A significant challenge for practitioners who are engaging in an accreditation process is understanding how to identify and structure relevant evidence of students' attainment. Contemporary engineering programmes draw on a rich array of complementary evidence streams, supporting the demonstration of accreditation requirements. Rubrics now provide the backbone for consistent judgements across modules and instructors, ensuring that similar standards are applied irrespective of who marks the work. Alongside these matrices, curated student portfolios chart longitudinal growth in design capability and encourage systematic reflection on learning trajectories. Peer evaluation systems further enhance the evidence base by sharpening students' collaborative awareness and offering additional perspectives on

individual contribution (Cole, 2023; Power & Tanner, 2023). Project-based learning assessments, grounded in real-world constraints supplied or developed with the industry in mind, furnish authentic artefacts that mirror professional practice (Farrell & Carr, 2019; MacLeod & van der Veen, 2020). Finally, detailed work placement reports, triangulated against feedback from workplace supervisors, supply robust confirmation of graduates' readiness for professional responsibilities. PEIs have responded by foregrounding programme-level mapping of direct (e.g., design outputs) and indirect (e.g., graduate surveys) indicators. Nevertheless, it should be acknowledged that there is a significant administrative burden imposed on HEIs in mapping learning outcomes to accreditation requirements.

Advancement in the mapping of learning outcomes to programme outcomes has been made using Natural Language Processing (NLP). Pauzi and Capiluppi (2023) developed a web-based tool for educators and university administrators that maps Learning Outcomes to PEI accreditation requirements. Advancements have also been made in streamlining the accreditation audit process. Hussain et al. (2020), in response to the challenges to accreditation auditing during the COVID-19 pandemic, developed an OBE framework and system capable of collecting, evaluating, and reporting continuous quality improvement data to ABET, allowing remote accreditation audits to take place.

3.4 Case study on the effective Integration of accreditation requirements into the curriculum

The principles outlined above are illustrated in the following case study, which demonstrates the effective integration of accreditation requirements into curriculum design and delivery. In 2015, Northern Border University's (Saudi Arabia) Industrial Engineering programme undertook a comprehensive curriculum redesign to align with the ABET accreditation requirements (Aoudia & Abu-Alqahsi, 2015). The initiative aimed to ensure that the programme met ABET standards for educational quality, continuous improvement, and competence requirements. The redesign process followed a structured, multi-level approach that connected ABET programme outcomes, programme objectives, module outcomes, and student learning outcomes into a coherent assessment and improvement system.

We would like to emphasize that the redesign began with a clear articulation of why change was necessary. Three levels of analysis guided this step:

- *high-level analysis.* review of programme objectives to ensure alignment with stakeholder expectations, including employers, alumni, faculty, and students.
- *mid-level analysis.* evaluation of the broad student learning outcomes, particularly those aligned with ABET's criteria, which emphasize abilities such as problem-solving, teamwork, ethics, and communication.
- *low-level analysis.* assessment of module learning outcomes to determine whether individual modules effectively contributed to the broader student learning outcomes.

This hierarchical approach ensured that the redesign was not superficial but deeply rooted in ABET's continuous improvement philosophy and ensured that ABET

outcomes were not treated as add-ons but were embedded throughout the educational experience.

The programme team aligned assessments with ABET criteria. Exams, quizzes, lab reports, and design projects were used to measure student mastery of module learning outcomes. Rubrics were standardized across modules to ensure reliable evaluation of ABET programme outcomes such as design ability, experimentation, and communication. Indirect assessment of student attainment was established using surveys of students, alumni, and employers, which provided qualitative insights into perceived strengths and weaknesses.

The programme ensured that students received a strong foundation in mathematics, science, and engineering fundamentals, as well as core industrial engineering knowledge in areas such as operations research, manufacturing systems, ergonomics, and quality engineering, culminating in a capstone design experience integrating multiple ABET outcomes, including teamwork, design under constraints, and professional responsibility. The redesign also emphasized modern engineering tools and technologies, aligning with ABET's expectations for contemporary practice.

ABET stresses the importance of engaging a broad range of stakeholders in defining and evaluating programme objectives. The programme team incorporated employer feedback to ensure graduates possessed industry-relevant skills. Alumni input was used to validate long-term effectiveness of the curriculum. Faculty workshops aimed to align teaching strategies with ABET expectations. This participatory approach strengthened the program's relevance and credibility.

The curriculum redesign described in this case study represents a comprehensive, systematic integration of professional accreditation requirements into an engineering programme. By aligning programme objectives and learning outcomes with ABET criteria, implementing robust assessment mechanisms and engaging stakeholders, the programme team established a sustainable framework for continuous improvement of the programme.

This case study demonstrates how ABET accreditation can serve as a catalyst for elevating educational quality and ensuring that engineering graduates are well-prepared for professional practice.

4 Challenges and future directions

4.1 Societal awareness

The underpinning fundamentals of engineering science and mathematics are well-understood, and, importantly, unlikely to change significantly in the lifetime of our students. This is empowering, as the development of understanding of as yet unknown technologies is based on the same principles as our understanding of the current state of the art, and others which may grow from the current state of the art. However, certain new topics have grown in prominence in recent years, and amongst these notable examples include studies on the importance of diversity and inclusivity (Murphy et al., 2025) and sustainability in accreditation requirements (Carthy et al.,

2023). These topics were previously not included in engineering curricula, as their deeper importance was not yet appreciated, but a recent willingness by those who govern accreditation frameworks to adopt a research-informed approach creates opportunities for this research to inform quality standards of the future. Now, it is generally accepted that engineers will be the people making decisions required to transform outcomes for people, and so a solid appreciation of what is *good, fair, and sustainable* practice is required. Notably, these topics seem to find traction with students, possibly because they are already more culturally adapted to the need for change than older generations. Regarding the teaching and assessment of transferrable skills in these areas there are several tensions to note:

- Topics relating to ethics and diversity and inclusion, are amongst the most challenging material to teach, and that students might face, both emotionally and cognitively. The development of effective teaching strategies is an imperative (Lawlor, 2021), so that the subjects are well integrated into curricula (Gwynne-Evans et al., 2021) and not treated as add-ons (Martin, 2020). The *International handbook of engineering ethics education* (Chance et al., 2025) goes some way to provide solutions to teaching such material, which the authors of this chapter endorse.
- The inclusion of these subjects in the programme is difficult, as they are quite different to other material. It can also be easy to trivialize them, compared to 'more technical' content, but this would be a serious error in curriculum design, given the equal weight given to technical and non-technical accreditation requirements by PEIs. This aspect is compounded by the zero-sum nature of teaching time in the curriculum.
- External factors exist beyond engineering which may erroneously see engineering only as an application of mathematics and science.

We feel that it is important to highlight that a broadly encompassing view of the role of the engineer in society has long been part of engineering education, it being incumbent upon academics, practicing engineers and PEIs to uphold and promote this view. The pressures endured by some *new* topics in the curriculum were not so long ago targeted at content such as sustainable practice, which few of us would argue the case for exclusion nowadays in any modern curriculum. It is essential that engineering graduates are effectively prepared to address evolving societal, and global challenges.

4.2 Digital trends

Engineering education has historically been at the forefront of adopting digital technologies to support learning, design, and professional practice. The rapid emergence of AI represents the latest stage in this evolution. For engineering programmes subject to accreditation, the integration of such technologies must be considered not only as a pedagogical innovation but also in relation to the attainment of required graduate attributes and competencies defined by PEIs.

Both the WA and EAFSG emphasize attributes such as problem solving, critical thinking, ethical responsibility, and the ability to use modern engineering tools

appropriately. AI systems may support these attributes when used as cognitive tools that assist exploration, modelling, and reflection. However, they also present a risk that students may rely on automated outputs rather than demonstrating their own competence. As a result, engineering educators must design learning activities and assessments that ensure students can still demonstrate authentic attainment of PEI accreditation requirements, even where AI tools are available.

A related challenge concerns academic and quality assurance, both of which fall within the scope of the accreditation requirements of many PEIs. The widespread availability of AI has created tensions between traditional assessment models and new forms of technologically mediated authorship. Attempts to detect AI-generated work through automated detection tools have proven inconsistent and, in some instances, unreliable (Cheng et al., 2025) reinforcing the need for all of us to rethink assessment design rather than relying solely on detection technologies.

At the same time, AI presents opportunities for personalised and adaptive learning support, potentially allowing students to engage with complex engineering concepts at their own pace. International policy guidance increasingly emphasises that the educational use of AI should prioritise transparency, accountability, and the development of critical digital literacy among learners (UNESCO, 2023). For engineering education in particular, this means ensuring graduates are not only capable users of advanced digital tools, but also reflective professionals who understand their limitations, ethical implications, and appropriate application within engineering practice, pursuant to the programme outcome requirements by PEIs.

4.3 Closing the loop on continuous quality improvement

A relevant problem regarding the way in which academia engages with the problem of usefully developing competencies and skills in undergraduates is that the effectiveness of teaching in preparation for practice is difficult to evaluate. Using the analogy of a system to control a process, a measurement is typically fed back to a controller, such that corrective action may be taken to account for deviation from a target output value, in many cases in near real time. However, in the academic context, little direct feedback is available on how teaching enables engineers at any stage of their career, let alone in real-time. At best feedback is partial, selective, and infrequent. As such control of the process tends to become *open loop*.

To 'close the loop' on this problem multiple options are available. For example, close analysis of graduate data (Phillips & Quilligan, 2024) and first-hand engagement with recent graduates operating in a range of professional roles can help inform programme leads on the effectiveness of provision (Aoudia & Abu-Alqahsi, 2015). Notably, close engagement with professional engineering institutions (for instance via accreditation activities) can act to drive wider industrial engagement, which will itself enable more opportunities to receive useful feedback. With PEIs stating that the most appropriate pedagogical method is the one that best delivers their accreditation requirements, a view on how well these requirements are met at every stage of an engineer's development would serve as compelling evidence of attainment.

In short, to improve the efficiency of teaching, we urge you to consider the authenticity of the material taught in terms of usefulness to a graduating engineer, as well as the effectiveness with which assessment drives the student to develop a particular skill area. Hence, we would make the following recommendations. Firstly, limit the number of competencies addressed in a single module so that each intended learning outcome can be meaningfully taught and rigorously assessed. A smaller number of clearly defined outcomes will allow you to design deeper assessments that provide convincing evidence of the attainment of accreditation requirements. Secondly, engagement with your PEIs during consultations, accreditation visits, and peer interactions should be seen as an opportunity to identify good practice in curriculum design, assessment, and skills development from a helpful friend or peer. Thirdly, actively seek examples of effective approaches from other practitioners of accredited programmes and consider how these might inform the continuous improvement of your own offerings. Fourthly, when accreditation frameworks are revised, make your voice heard by contributing to consultations led by PEIs and related bodies. Your input ensures that accreditation requirements remain practical, evidence-based, and aligned with the realities of engineering education. Engagement in these consultations also helps communicate the importance of research-informed approaches to curriculum and competence development. Finally, engineers are expected to be prepared as lifelong learners during their education and initial professional development, so place an emphasis on developing the habits and skills associated with lifelong learning in your students early on in their education. Introducing your students to reflective practice, continuing professional development, and self-directed learning early in their undergraduate education helps prepare students for careers in which professional competence must continually evolve.

5 In closing

For the past two decades, engineering accreditation has increasingly adopted an outcomes-based approach that focuses on what graduates are able to do in terms of competencies and skills. Rather than prescribing detailed curricular inputs, related to the number of practice hours or the length of practice placements, accreditation frameworks articulate a set of programme outcomes that practitioners must evidence through their curriculum design, teaching practices, and assessment strategies. This principle-based model has become a defining feature of engineering education globally and has been widely disseminated through international agreements and accreditation frameworks.

In contrast to many other professions, where programme approval processes remain more strongly input-driven — specifying required contact hours, subject coverage, or curriculum structures — engineering accreditation places primary emphasis on the demonstrable attainment of competencies and skills relevant to professional practice. This shift has enabled greater flexibility for programme providers while ensuring that graduates meet internationally recognised standards of engineering competence.

For you as practitioners, this approach places responsibility on programme teams to design coherent curricula, align learning outcomes with accreditation requirements,

and implement assessment strategies capable of evidencing graduate capability. When implemented effectively, outcomes-based accreditation provides a robust mechanism for supporting the development of competent engineers prepared for contemporary, rapidly evolving professional contexts.

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AI statement

During the preparation of this work, the authors used OpenAI, GPT 3.5 to structure the case study on the effective integration of accreditation requirements into the curriculum. Once a structure had been established, the authors wrote the substantive content of the case study. They take full responsibility for the content of the publication.

Contributor statement

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ⁱ an external examiner is someone from outside a student's own school, college, or university who judges an exam. (Cambridge Dictionary, 2025).

1.5

Transferable Competencies and Skills: The Framework Underpinning this Handbook

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This final chapter of Part 1 introduces you to the transferable competency and skills framework on which this handbook is based and how it is situated within accreditation requirements and relevant criteria of professional bodies. It explains why we subscribe to the UNICEF definition of transferable competencies and skills as those needed to adapt to various life contexts, which people can potentially transfer to different social, cultural, or work settings. Building on this, we explain the selection and definition of the transferable competencies and skills employed, using the current UK Chartered Engineer Standard as defined in the UK-SPEC as our point of departure. As a result, the following competencies and skills were included: project management, meeting skills, risk analysis and risk management skills, leadership skills, teamwork, oral presentation skills, written communication and reporting skills, visualisation skills, spatial ability, and representational literacy, interpersonal communication skills, feedback skills and feedback literacy, self-regulation, the adaptability for change, resilience, information literacy skills, autonomous motivation, learning beliefs and strategies, and initiative and perseverance. For each included competency and skill, a working definition is provided to aid you when using this handbook. We also address what competencies and skills were not included and why. The chapter contains a reflection on the sustainability of competency frameworks and that revisiting their purpose and context on a regular basis is important, although individual transferable competencies and skills will likely remain a stable component of any future engineering curriculum. The chapter ends with reiterating SEFI's mission to educate holistic engineers and introducing our view on how to use this handbook.

1 Introduction

As the previous chapters have shown you, the academic discourse on competencies, skills, and competence models has been ongoing for decades in both national and international contexts, employing a variety of terms (e.g., key competencies, core qualifications, transversal skills). This discourse is broad and heterogeneous and has been synthesized in several comprehensive overviews (e.g., Dippelhofer et al., 2025; Johannsen, 2025; Kotsiou et al., 2022), encompassing frameworks that are partly conceptual and partly empirically grounded.

It is important to realise that these frameworks target different audiences (e.g., educators, learners, university leadership, policymakers, industry) and vary in their methodological approaches (e.g., qualitative analyses, Delphi studies, mixed methods), stakeholder involvement (e.g., experts, NGOs, employers), instruments used (e.g., surveys, interviews, scenarios, taxonomies), and other dimensions (see, for instance, Ehlers & Eigbrecht, 2024). This has resulted in national and international discourses that are characterized by plurality and fragmentation. Their thematic focus ranges from competence-oriented continuing education formats to strategic governance frameworks and collaboratively developed future skills, as highlighted in Chapter 1.2 and Chapter 1.3.

As a result of these different frameworks, standards have been developed that we as educators must ensure our graduates can meet when they graduate and start working as engineers in the field. You might have seen in Chapter 1.4 how these frameworks have resulted in these standards and how they are upheld by regulatory and accreditation bodies, be it government-based or professional bodies.

Therefore, for this handbook, we had to decide which framework and terminology to use. In this chapter, we will set out which definition of transferable competencies and skills we will use within the context of this handbook. We will introduce you in detail to the competency framework for transferable skills on which this book is based, and why we selected this framework. We will also detail the underlying competencies and skills that are part of this framework and how we define them within this handbook. Hopefully, this will enable you to place the content of this manual within your context. Finally, we discuss how we envision the competency framework, and the underlying competencies and skills are to be used by you, the reader, to help you get started.

2 Transferable competencies and skills definition

As Chapter 1.2 has explained, many different terms and definitions exist of what we in this handbook call transferable competencies and skills. This is why we decided to select a definition that is universally and widely used, also outside higher education and engineering education, to allow for a broad understanding given the increase in interdisciplinarity and transdisciplinarity within education and the potential global readership of this handbook.

After looking at many definitions, we settled on the definition by the UNICEF as a global leader in promoting the attainment of competencies and skills through

education. UNICEF defines transferable competencies and skills as those that are needed to “*adapt to various life contexts and that people can potentially transfer to different social, cultural or work settings*” (UNICEF, 2022, p. 3). It subdivides these into cognitive, social, and emotional skills (UNICEF, 2019). Although in the English language, distinctions in definition can be made between the words *competency*, *competence*, and *skills*, in many other languages, only one word exists for all three terms (Guerrero & Del Los Rios, 2012; Kearns et al., 2016). As this handbook is intended for an international audience, we will use the umbrella term of *competencies and skills* throughout and interchangeably.

3 Competencies and skills framework used in this handbook

As stated before, a vast multitude of competency frameworks exist, for a variety of audiences and purposes, some very broad, discipline-non-specific frameworks, some just specific to engineering. What all frameworks have in common is their aim: to better prepare both the current and future workforce for the challenges that lie ahead.

Many such frameworks only cover transferable competencies and skills and do not always explicitly link or embed their framework within the wider set of competencies and skills in the science and engineering domain that graduates must possess. These new transferable competencies-only frameworks are almost the opposite of what was happening in many engineering programmes prior to the 2000s which focussed mostly on technical competencies and skills. Whilst there were plenty of calls from industry for the need of engineering graduates to possess these competencies and skills, they were not formally included in the accreditation standards of the time.

Transferable competencies and skills were not included as a formal part of accreditation requirements in many engineering programmes worldwide until 2000 when the Accreditation Board for Engineering and Technology, now known as ABET, started doing so (Engineering Accreditation Commission, 2000). The introduction of the ABET 2000 criteria stemmed from pressure from industry to include these competencies explicitly, most notably by John McMasters from the Boeing Company (McMasters & Lee, 1996).

Parallel initiatives to this were taking place in Australia (Engineers Australia, 2013) and among member states of the European Higher Education Area (EHEA), who established a set of common descriptors for education outcomes, known as the Dublin descriptors, which first explicitly mentioned transferable competencies such as communication skills (Bologna Working Group on Qualification Frameworks, 2005). It was then up to every individual EU member state to create its own frameworks for accreditation and recognition purposes.

The creation of the Dublin descriptors and the European Qualification Framework (EQF), an eight-level, learning outcomes-based framework for all types of qualifications that serves as a translation tool between different national qualifications frameworks, has been instrumental in allowing for a more coherent, comparable, and compatible higher education process within the EHEA, fostering collaboration and exchange. In the Netherlands, for example, a set of criteria for bachelor and master

curricula in engineering at Dutch research universities was developed as a result, which explicitly included some transferable competencies as a requirement for the first time (Meijers et al., 2005). These criteria are still in use today.

Internationally recognised accreditation bodies first mandated transferable competencies and skills, driving formal introduction into engineering curricula. This shift subsequently launched an entire field of educational research focused on how to best implement these skills. For those interested in a historic overview of research and development of engineering curricula prior to the establishment of the ABET 2000 criteria, including transferable skills, we refer to the seminal work by John Heywood on engineering education research (2005), in particular Chapter 2 on aim and objectives. We showcase this development in Chapter 1.3 of this handbook, where the authors introduce and discuss different frameworks on transferable competencies and skills developed over the past 20 years.

Whilst the discourse on competencies and skills and the frameworks encompassing them continues, for this handbook, we have decided to narrow our focus to a framework that is directly relevant to engineering graduates in any discipline and has been created by and for engineering professionals. This choice was motivated by the notion that in many countries the engineering profession is actively involved in the accreditation process and in formulating the degree requirements for engineering, as is explained in detail in Chapter 1.4.

The framework within which the transferable competencies and skills were defined also had to include science and engineering competencies and skills to ensure that the necessary interplay between the different sets of competencies and skills that engineers need to have is not overlooked.

To find such a framework, we turned to the many professional bodies in engineering that exist worldwide, be it discipline-oriented, such as IEEE (Institute of Electrical and Electronics Engineers), SAE International (formerly the Society for Automotive Engineers), and ASM International (formerly the American Society for Metals), or organised through national bodies, such as Engineers Ireland, the Engineering Council (UK), Ie-Net (Belgium), Ordem dos Engenheiros (Portugal), Verein Deutscher Ingenieure (Germany), Federacja Stowarzyszeń Naukowo-Technicznych Naczelna Organizacja Techniczna (Poland), and Koninklijk Instituut voor Ingenieurs (KIVI) in the Netherlands, who collaborate internationally in networks such as Engineers Europe and the International Engineering Alliance (IEA).

What all these bodies have in common is striving to affirm and develop the professional identity of engineers. Many of these institutions, depending also on local regulations, are involved in the accreditation of their national engineering programmes and the mutual recognition of these accredited degree programmes, as was explained in Chapter 1.4. Many professional bodies in the English-speaking world offer the possibility for their members to become professionally registered with their professional body, with a variety of different types of registrations, with the highest status being that of Chartered Engineer (this titled is used in Ireland, the United

Kingdom and more recently also the Netherlands, in other countries the term Professional Engineer is used). As detailed in Chapters 1.3 and 1.4, having this registration allows the holder to have their qualification recognised as equivalent in other Washington Accord signatory countries. This is often needed if an engineer wants to progress to more senior roles in their career (Engineering Council, 2020).

The requirements one must meet for professional registration have been laid down in official standards in many countries, such as Australia, Canada, Ireland, the Netherlands, and the United Kingdom. These standards are often also used as a basis for the accreditation process of individual engineering programmes and are recognised under the various accords as discussed in Chapter 1.4. Hence, for our framework, we have decided to use the Chartered Engineer Standard as specified in UK-SPEC: The UK Standard for Professional Engineering Competence and Commitment (4th edition), as published by the Engineering Council (2020) is our starting point. This framework is similar to the Chartered Engineer Standards of Engineers Ireland and of the KIVI in the Netherlands, and in line with the EUR-ING SPEC of Engineers Europe (formerly FEANI) and its EUR-ACE label.

The Engineering Council (2020) centres UK-SPECs around five key areas:

- A. Knowledge and understanding
- B. Design, development, and solving engineering problems
- C. Responsibility, management, and leadership
- D. Communication and interpersonal skills
- E. Professional commitment

For each of these areas UK-SPEC defines demonstrable behaviour and abilities (that is, competencies and skills) that applicants must prove in order to be considered for professional registration. We felt that UK-SPEC was the most suitable framework as a point of reference. Firstly, because it forms a bridging function between higher education and professional practice. Secondly, because it also aligns well with scaffolding effects in the didactical and pedagogical design of competency and skill development. Thirdly, its central focus is on what qualifies someone as an engineer in a discipline-unspecific manner, which sets it aside from thematic competency frameworks in engineering education that focus on what competencies and skills an engineer should have to be competent in a specific area, such as competency frameworks for sustainability or entrepreneurship. Finally, it is publicly accessible, well established, and well-documented, while also compatible and transferable internationally.

For this handbook, we used the last three areas of UK-SPEC as a base for our selection of transferable competencies and skills to be included, as these were the areas which in our opinion focused primarily on transferable skills. We adjusted the wording slightly to eliminate any confusion, which resulted in three themes which form the framework of the handbook.

Theme I. Responsibility, project management, and leadership

Theme II. Communication and interpersonal skills

Theme III. Professional commitment and lifelong learning competencies

Based on the demonstrable behaviour and abilities listed in UK-SPEC, we created the list of individual competencies and skills that have been included in the handbook.

4 Transferable competencies and skills included in this handbook

In this section, we will detail, per theme, the included competencies and skills and how we define them within the context of this handbook. Research has shown that competencies and skills are often not explicitly defined, which causes confusion when wanting to implement competencies and skills in your own context (Leandro Cruz et al., 2019). For a deep dive, we recommend you consult Chapter 1.2. How you could teach each of these competencies and skills will be discussed in dedicated chapters in Part 2 of this handbook. For reference purposes we refer to the relevant chapter with each definition.

4.1 Theme I. Responsibility, project management, and leadership

The theme of responsibility, project management, and leadership, centres on the engineer taking responsibility and being in the lead within an operational and process context. The included competencies and skills in this section are project management skills (on a process level), meeting skills, risk analysis & risk management skills, and Leadership Skills.

For *project management* (on a process level), discussed in detail in Chapter 2.2, we use the definition of the Association of Project Management (2024): “*the ability to apply processes, methods, skills, knowledge and experience to achieve specific project objectives according to the project acceptance criteria within agreed parameters*”.

We define *meeting skills* (Chapter 2.3) as a set of teachable professional competencies that enable engineers to prepare for, participate in, lead, and follow up on meetings effectively. These skills extend beyond generic communication abilities, encompassing technical precision, facilitation strategies, structured decision making, documentation standards, and inclusive participation practices tailored to engineering environments (Changpueng & Pattanapichet, 2024; Galster et al., 2024).

For *risk analysis and risk management skills* (Chapter 2.4), we adopt the definition by NASA (2007): the ability to carry out a risk analysis and manage and mitigate identified risks in engineering design and operations.

Finally, for *leadership skills* (Chapter 2.5), we follow the definition of the Systems Engineering Body of Knowledge (SEBoK, 2024): “*The ability to create the environmental conditions conducive to good performance: support of shared understanding, innovation, problem-solving, resilience and learning*”.

4.2 Theme II. Communication and interpersonal skills

The second theme, communication and interpersonal skills focuses on the competencies and skills engineers need to communicate and work with others. These include teamwork, oral presentation skills, written communication and reporting skills, visualisation skills (in combination with spatial ability and representational literacy),

interpersonal communication skills (including awareness of others, one-on-one communication, and participation in meetings and groups), providing feedback, and feedback literacy.

Teamwork (Chapter 2.6) refers to coordinating individual contributions with others when working together in teams. It has many different aspects that can be considered, such as collaborative goal setting, diverse, intercultural, and inclusive teamwork, engagement, goals setting in teams, and multi-, inter- and transdisciplinary teams as defined in detail by Leandro Cruz and Saunders-Smiths (2019).

Under *oral presentation skills* (Chapter 2.7), we include *presentation skills*, defined by Leandro Cruz and Saunders-Smiths (2019, p. 13) as “*the ability to give a clear, organised and logical speech and answer questions adequately and with elaboration*”, *the quality of presentation method*, defined as “*the ability to develop presentation methods and mediums depending on the topic and target group*”, and *pitching skills*, “*the ability to convey and persuade audiences within a short 1–3-minute speech*”.

We define *written communication and reporting skills* (Chapter 2.8) as “*the ability to develop a logical, accurate, detailed, and organised written product using the appropriate language and style without grammar mistakes and with accurate references*” (Leandro Cruz & Saunders-Smiths, 2019, p. 17).

For *visualisation skills* (Chapter 2.9), we derived our definition from Sorby et al. (2013) and Raju and Sorby (2024) as the active, applied processes that draw on spatial ability to construct, interpret, and work with images in order to understand and solve engineering problems. These skills form a core triad with *spatial ability*, defined as the cognitive foundation, and the capacity to generate, retain, and mentally manipulate visual images in two- and three-dimensional space (Buckley et al., 2018; Lohman, 1994) and *representational literacy* which addresses how visual-spatial thinking is externalised, communicated, and refined. It refers to proficiency in creating, interpreting, and working flexibly with the visual language of engineering, such as via technical drawings, schematics, free-body diagrams, and digital models (Johri & Lohani, 2011).

In our definition of *interpersonal communication skills* (Chapter 2.10), we follow Leandro Cruz and Saunders-Smiths (2019) by seeing this as the combination of *listening skills*, defined as the “*ability to attend closely to verbal and non-verbal messages to ensure accurate interpretation*”, *adaptive communication ability*, defined as the “*ability to build trust and sustain constructive relationships over time*”, and the *interconnection/interrelation ability*, defined as “*the ability to build and retain formal and informal relationships or networks*” (Leandro Cruz & Saunders-Smiths, 2019, p. 13).

With regard to *providing feedback* (Chapter 2.11), we define feedback as “*a process through which learners make sense of information from various sources and use it to enhance their work or learning strategies*” (Carless & Boud, 2018, p. 1315).

Finally, we refer to *feedback literacy skills* (Chapter 2.12) as “*the understandings, capacities and dispositions needed to make sense of feedback information and use it to enhance work or learning strategies*” (Carless & Boud, 2018, p. 1316).

4.3 Theme III. Professional commitment and lifelong Learning competencies

Finally, the third theme on professional commitment and lifelong Learning competencies, focuses on the engineers themselves. These are the competencies and skills engineers need to be able to continue to develop themselves and grow. This is often referred to as lifelong learning, which encompasses all learning activities undertaken throughout life with the aim of improving knowledge, skills, and competences, within personal, civic, social, or employment-related perspectives (Commission of the European Communities, 2001; Van den Broeck et al., 2024). Competencies and skills included in this theme are self-regulation, self-reflection, and self-direction, adaptability for change or change management, resilience and the ability to cope with changes, failures, and success, information literacy skills, autonomous motivation, learning beliefs and strategies, initiative, and perseverance.

We define *self-regulation* using the well-known definition of Zimmermann (2002, p. 65-66) as “*learners being proactive in their efforts to learn because they are aware of their strengths and limitations with learning and because they are guided by personally set goals and task-related strategies involving self-motivation and behavioural skill development and involves the selective use of specific processes that they will personally adapt to the learning task*”.

For *self-reflection*, we turn to the American Psychological Association (2018c) which defines this as “*examination, contemplation, and analysis of one’s thoughts, feelings, and actions*”.

We use the definition of Garrison (1997, p. 18) for *self-direction* as “*an approach where learners are motivated to assume personal responsibility and collaborative control of the cognitive (self-monitoring) and contextual (self-management) processes in constructing and confirming meaningful and worthwhile learning outcomes*”. All three concepts are included in Chapter 2.13.

For the definition of *adaptability for change or change management* (Chapter 2.14), we follow Hall and Chandler (2005, p. 163): “*a learner’s adaptability involves identifying qualities which are critical for future performance and being both willing and able to make personal changes to meet those needs in a proactive way*”.

For *resilience* or ability to cope with changes, failures, and success (Chapter 2.15), we again turn to the American Psychological Association (2018b) which defines this as “*the process and outcome of successfully adapting to difficult or challenging life experiences, especially through mental, emotional, and behavioural flexibility and adjustment to external and internal demands*”.

In the context of this handbook (Chapter 2.16), we define *information literacy skills* as “*a set of abilities to identify the need for information, find and evaluate it effectively, and use it in an ethical and legal manner to solve engineering problems. It underpins*

lifelong learning and supports the critical evaluation of automated information sources" (ACRL, 2006).

Discussed together in one chapter (Chapter 2.17) in Part 2, we define *autonomous motivation* as intrinsic motivation, doing something because it is inherently interesting or enjoyable or motivating oneself by focusing on positive external factors, derived from Ryan & Deci (2000), *learning beliefs* as a person's subjective judgements about a relation between learning and his or her values or attributes (Fishbein & Ajzen, 1975), and *learning strategies* as "*an individual's way of organizing and using a particular set of skills in order to learn content or accomplish other tasks more effectively and efficiently in school as well as in non-academic settings*" (Schumaker & Deshler, 1992, p. 22).

The final two competencies in this theme are perseverance and initiative (Chapter 2.18). Here, *perseverance* is defined as "*the quality or state of maintaining a course of action or keeping at a task and finishing it despite the obstacles (such as opposition or discouragement) or the effort involved*" (American Psychological Association, 2018a), and *initiative* as "*behavior characterized by its self-starting nature, its proactive approach, and by being persistent in overcoming difficulties*" (Frese & Fay, 2001, p. 134).

For easy reference, all definitions can also be found in the Glossary at the end of this handbook.

4.4 What was not included

If you were to go through the list of demonstrable behaviours and abilities of the UK-SPEC, you will notice that we have not included everything listed there. In this section, we explain what we decided not to include and our motivations. We would like to emphasize that our decisions to not include a certain skill or skill set should not be seen as scientific judgement based on undeniable proof of what is and is not a transferable competency or skill, on what is or what is not important, or what is a single competency or skill and what is a subset. That is not the debate we are aiming to settle in this section, nor is it a debate that will likely ever be definitively settled; it will likely always be an ongoing academic discourse. Rather, the aim of this section is to simply set out the choices we made and why, so that you as reader are aware of these choices and our motivations for making them. This information may help you make your own choices if needed.

As this handbook explicitly deals with transferable competencies and skills, we have not included any competencies or skills that are often seen to be implicitly or explicitly part of discipline-related engineering, science (e.g., natural sciences, computing), and mathematics modules, such as analytical skills, problem solving skills, computational thinking, design thinking, research skills, and computer-aided design (CAD) skills. In addition, some of these skills, such as computational thinking, are rapidly developing from what was seen as a technical skill (Aho, 2011) within computer science into its own competency framework with its own set of (technical and transferable) competencies and skills applicable beyond the field of computer science. As suggested

by Jeanette Wing in 2006, it includes four pillars: problem decomposition, pattern recognition, abstraction, and algorithmic thinking (Wing, 2006, 2011).

We also did not include creativity as an explicit transferable competency as it is not specifically listed as a competency or skill in the UK-SPEC but rather as a method, in line with observations by Cropley (2015) that many see creativity as a natural part of problem solving within engineering. Cropley expresses concern that by not explicitly including creativity as a method, programmes risk focusing excessively on narrow and deep technical specifications, with little or no room in the curriculum for developing the ability to think and act creatively. This is perhaps also a skill that should fall in the transdisciplinary category of competencies and skills as detailed in the SEFI position paper on Competencies and Skills in Engineering Education (SEFI, 2025). We see these as different from transferable skills with transdisciplinary competencies and skills defined as those that *"[a]fford an outward facing, broader appreciation and active engagement with traditional and non-traditional sources of knowledge from both academic and non-academic domains. These encompass skills related to ethical decision-making, sustainability and social responsibility"* (SEFI, 2025, p. 2). In this handbook, we will not cover transdisciplinary competencies and skills.

We also did not include innovation and entrepreneurship skills or sustainability skills. There are two reasons behind this decision. First, much like creativity, these skills are explicitly categorised as transdisciplinary competencies and skills in the SEFI (2025) Position Paper. Second, in our view, they are not referred to in the UK-SPEC framework as a competency or skill, but rather as a method: *"Chartered Engineers develop solutions to complex engineering problems using new or existing technologies, and through innovation, creativity and technical analysis"* (Engineering Council, 2020). As transdisciplinary skills, they are large umbrella concepts with their own framework of corresponding competencies and skills that deserve attention in their own dedicated handbooks, even though there may be an overlap with the required transferable competencies and skills. An example is the entrepreneurship competence framework of the European Union, EntreComp (European Commission, Joint Research Centre, 2016) and its 'sister' framework GreenComp (European Commission, Joint Research Centre, 2022). We believe teaching and assessing these competencies to be different from the competencies and skills in this handbook and have therefore not included them.

The UK-SPEC also explicitly mentions language skills and more specifically that an engineer must be able to communicate in English as one of the official languages of the United Kingdom. Whilst part of this is implicitly covered in Theme II in the oral and written presentation and reporting skills, the learning of languages, if offered to engineering students at all, is often taught as a separate module in addition to or outside the formal curriculum by linguists who are trained to do so. In many countries where English is not the first language, students will already have been taught English in secondary school to a good level, often enabling them to follow university classes in English. As a result, in many programmes, the learning of languages is not included

as a mandatory and integrated part of the engineering curriculum. Hence, we decided to exclude this skill from the handbook.

We also did not include health and safety and environmental awareness as transferable competencies or skills in this handbook. Whilst implicitly covered in certain competencies and skills in Theme I and III, the more in-depth teaching of such skills is too discipline- and country-specific.

Finally, and perhaps controversially to some, we also did not include ethics as a transferable competency or skill. Recently, an excellent handbook on teaching ethics in engineering education has been published. We therefore refer the reader who is interested in the actual teaching of ethics in engineering education to the *Routledge international handbook of engineering ethics education* (Chance et al., 2024). The handbook was initiated and overseen by SEFI's Ethics SIG and is a great resource for anyone interested in teaching ethics.

5 How to use this competency framework and the underlying transferable competencies and skills

If you have read the previous chapters, then you know that this is not the only framework out there. We also would like to stipulate that the framework presented in this chapter is NOT a 'gold standard' that must be adhered to at all costs. We chose this framework because we felt it is the most generic framework within engineering and would resonate with any engineering educator regardless of discipline or background. What we do hope you will take away is that acquiring transferable skills is an important part of the education of engineers, and that this notion is not only supported by scientific research, but also by engineering professionals, their employers and their representatives.

We hope you will see the framework presented as a tool, a scaffolding, a handle or a guide, or all the previous, to help you position all or some transferable competencies and skills within your teaching and your curriculum. We intend for you to use this framework and this handbook to help you identify your needs in helping students reach their educational goals in your context, within your institution, and in your country, within the context of the applicable accreditation requirements for your institution.

5.1 The sustainability of the competency framework and the definitions used in this handbook

As with any framework, ours is a snapshot in time and not a set of eternal truths carved in stone. The same goes for the individual competencies and skills it describes. We live and teach in an era of disruption and sociotechnical transformation. While overarching goals like the Sustainable Development Goals (SDGs), as developed by the United Nations (2015), offer a helpful compass through to 2030, we believe — as outlined in SEFI's position paper — that shaping engineering education to be professional, responsible, impactful, and future-proof requires a blend of technical, transferable, and transdisciplinary competencies and skills.

Each of these categories plays a different role. Technical competencies and skills respond directly to fast-paced technological advancements. Transdisciplinary competencies and skills connect with stakeholders from across society, industry, and politics, and are shaped by various interests and systemic dynamics. Transferable competencies and skills, we believe, offer a kind of persistence as they may be more stable over time.

Of course, even transferable competencies and skills are rooted in ever-evolving theoretical frameworks and shaped by shifting contexts. They reference and reflect knowledge domains and practical demands that change over time or sometimes even abruptly. Still, they represent core human capacities that are not only essential for the engineering profession, but also fundamental for personal growth and development. By strengthening engineers' sense of agency, they also foster a deeper experience of self-efficacy. In that way, they contribute meaningfully to both personal development and the broader skillset engineers need to navigate technical and technological challenges across projects, between organizations, and within societal contexts.

That said, values and goals, both individual and collective, have changed over time, and there is no reason to think they will not continue to do so. For that reason, even though transferable competencies and skills feel more enduring, they too must be continually re-examined. Only the test of time, that will need to be measured against evolving social frameworks and the expectations of professional bodies, will show which aspects prove truly resilient, persistent, and relevant. In Part 5 of this handbook, we offer various chapters on how you can evaluate this.

We expect that our framework, definitions, methods, and examples will continue to be of use in shaping engineering education but will not last in this exact form for eternity. Therefore, we welcome their discourse, contestation, and evolution through original research and new, innovative teaching and learning approaches. We hope that future educators and researchers will make use of the open access status of this publication to update and create relevant future versions of this handbook.

5.2 *But my situation is different from yours*

At this point, we would like to emphasise that the framework, just like the individual competencies and skills, is an abstraction that must be adapted to be applicable in specific circumstances and situations. This means that this handbook is not a manual to be followed to the letter but rather offers guidance and inspiration on how these competencies and skills can be developed in your own teaching. What matters most is that we do not aim to provide standardised knowledge but to enable students to develop a form of agency that prepares them to be a professional engineer as much as a responsible citizen, i.e., to become an agentic, holistic engineer.

We therefore encourage you to have the courage to leave behind the safety of either right or wrong, black or white, and to step forward into the grey area between those poles. Precisely because there is no single right or wrong, this is a learning journey that we, as educators, embark on together with our students. This handbook offers a wealth of ideas to help you unlock these potentials. At the same time, each situation

is as individual as the students we work with. There is no one-size-fits-all solution. This applies to the framework (which is why, as shown in Chapter 1.3, there are many frameworks), as well as to the individual competencies and skills covered in Part 2.

6 In closing

Teaching transferable competencies and skills depends on multiple factors, such as the discipline, the number of participants in a module, room facilities, availability of digital and non-digital tools, study regulations, educators' resources, and many more. This handbook is intended to provide orientation within this resulting diversity of possibilities and to offer suggestions, provide references, enable deeper engagement, raise awareness of potentials, and above all, encourage experimentation and further development of one's own teaching. We implore you to browse the handbook for an inspirational overview as well as delve deeper into any and all matters of interest to you, to build on the expertise and insights offered in this handbook and pursue further readings and resources. Most of all, and we cannot stress this enough, we encourage you to try new ways of teaching beyond the trodden pathways and explore strategies, methods, and tools provided in this handbook. Do let us know how you get on!

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Part 2

Embedding Transferable Competencies and Skills in Your Classes

2.1

Introduction to Embedding Individual Transferable Competencies and Skills

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Keywords: *transferable competencies and skills, educational development, engineering curriculum, academic staff development, instructional design, engineering education practice*

This introductory chapter presents Part 2 of the handbook, dedicated to individual transferable competencies and skills. It outlines the conceptual foundations of transferable competencies and skills in academic teaching, with a focus on engineering education, and explains the common structure of all chapters in this section. The transferable competencies and skills are then placed within the broader framework of the handbook, linking them to the theoretical considerations in Part 1 and to subsequent discussions on assessment, evaluation, and programme-level development in Parts 3 to 5. This introduction concludes with a call to action, encouraging you as an educator to embark on a shared learning journey with your students.

1 Objective of Part 2: From concept to application in the classroom

The objective of this part of the handbook is to provide you, in your role as engineering educator, with evidence-informed chapters about teaching transferable competencies and skills. The chapters in this part are written to provide practical guidance, tested methods, and proven approaches for integrating these competencies and skills into your teaching practice and supporting their development in students. In this part, we aim to explain how such integration can be done intentionally, strategically, and in an informed, learning outcome-oriented way, so that it truly contributes to the development of transferable competencies and skills in students. Our focus is on engineering education; our intention is to share effective, constructive methods and inspire further development of successful interventions. Part 2 focuses on 17 individual transferable competencies and skills. Each chapter defines and describes one of these and offers examples of how and where it can be embedded in teaching and learning. Wider discussions of curriculum design and programme-level strategies appear in Part 4 of the handbook.

This handbook builds on the SEFI Position Paper (2025), which distinguishes between technical, transferable, and transdisciplinary competencies and skills. A more detailed discussion of the terminology can be found in Chapter 1.2, while Chapter 1.3 provides a contextual overview of the various frameworks relevant to engineering education. In this handbook, we understand transferable competencies and skills as those that are needed to *"adapt to various life contexts and that people can potentially transfer to different social, cultural or work settings"* (UNICEF, 2022, p. 3). They are essential for engineering professions and practices and complement technical or disciplinary as well as transdisciplinary competencies and skills that involve, in a nutshell, active engagement with traditional and non-traditional sources of knowledge from academic and non-academic domains (SEFI, 2025). However, we do not cover technical or transdisciplinary competencies and skills in this handbook. Our points of reference and theoretical foundations are presented in detail in Chapter 1.5, in which we also explain the classification and selection criteria for the transferable competencies and skills included in this handbook.

With Part 2, we move from these broader reflections and frameworks to a closer look at individual transferable competencies and skills, focusing on practical aspects and questions of implementation within specific modules. Our commitment in this section is to place practical guidance for educational practice at the centre. You can expect to find hands-on insights and support for your work as an educator.

2 How Part 2 chapters are structured and how they can be used

All chapters in Part 2 follow the same structure. Instead of beginning with a traditional introduction, each chapter opens with a comprehensive definition, i.e., a clear and detailed explanation of the competency or skill under discussion. This approach ensures a shared understanding and allows the authors to be transparent about how they define the concept, before exploring arguments and different ways of

implementation in higher education, and particularly in engineering education. The definition may include the core concept of the competency or skill, relevant theoretical references, frameworks, or models, key authors or foundational works, etymological or semantic considerations, connections to or overlap with other skills or competencies, essential components or dimensions, and contextual variations that influence how the skill is understood and applied. What you can expect, in short, is a solid foundation for the discussions that follow in each chapter. This also serves as a helpful guide to understanding the essence of each competency or skill so that you can make an informed decision about whether it is relevant for you and your own educational context.

The second section of each chapter presents a comprehensive argument. Here, the authors explain why the competency or skill matters. To that end, they ground their claims in empirical evidence and demonstrate its relevance for engineering education. This section shows how the competency or skill can or should be developed in learners and provides a well-founded rationale for its inclusion in educational practice. The argument may address a range of aspects and is designed to be both informative and useful for you. It may include a discussion of research methods used to study the skill, explanations of how these methods help to generate evidence, the presentation of data, statistics, or empirical findings, a demonstration of relevance for engineering students, or an exploration of its importance to practising engineers in their professional roles. Throughout this section, the focus is on providing arguments that are supported by literature, research, or tested practice, in order to answer the question of why this skill or competency is relevant for engineering education and for professional engineers alike.

Thirdly, each chapter then focuses on implementation and provides practical guidance for you as an educator by helping you to integrate the discussed competency or skill into your own teaching or educational practice. You may find that the authors address any or all of the following aspects: the context in which implementation is appropriate and whether the skill is best developed in an individual module, across several modules, or as part of a full programme, as well as the student's level of study for which an intervention is suited, and whether students should be at undergraduate or graduate level (first, second and third-cycle degree programmes). You may learn if the skill requires progressive development across study phases, be inspired to reflect on assumptions about teaching or learning methods, which can be aligned with the arguments and literature discussed in the previous section, and be reminded of specific module design elements that you may need to consider supporting effective implementation. Moreover, you will find practical examples to serve as inspiration and guidance. Some chapters will highlight challenges and offer possible solutions, others will list necessary or helpful resources such as textbooks, online materials, tools, or other supporting measures that can be integrated into modules to foster the development of competencies and skills. Importantly, this section also considers what factors should be taken into account if you want to adapt examples and use cases across institutions or in different contexts. Overall, this section, as much as the next,

aims to offer actionable guidance and provide ideas and strategies you can use directly in your own modules and settings.

The fourth section of each chapter covers recommendations for implementation and learning. It is designed to provide you with actionable guidance, offering concrete ideas and strategies that can be applied easily in your own teaching and educational context. This section focuses on practical insights and instructions, grounded in research, evidence, and tested experience. It includes concise lists of key recommendations for implementing the competency or skill in engineering education settings, different rationales for these recommendations linked back to the evidence and arguments presented earlier, a list of dos and don'ts that highlight good and best practices explaining why they matter, as well as common pitfalls or mistakes to avoid. By reflecting lessons learned from case studies, experience, or research, the authors offer insights into what has proven effective in practice. They point out critical factors that require your attention when implementing these competencies and skills in your modules. Furthermore, you will find aspects to consider when acting on the guidance provided, for example, how recommendations might vary depending on class size, available resources, or programme structures; how attention to institutional and cultural aspects may influence outcomes; or how to incorporate and value student perspectives. In addition, this section offers reflection on how recommendations may evolve through iteration and continuous improvement, including methods such as ethical risk analysis, peer feedback, and resilience-based interventions, which are discussed in chapters 2.4, 2.11, and 2.15, respectively. These recommendations will also help you to address different levels of study and learning progression, as well as scaffolding effects relevant for your didactical design in light of your particular context. All recommendations are either evidence-based or grounded in well-documented professional experience. The goal is once again to equip you with clear and actionable guidance that will help you integrate competencies and skills effectively into your engineering education practice.

Finally, where possible, each chapter offers you recommendations to help you deepen your understanding of the respective competency or skill beyond the scope of the chapter. They offer a path forward for those who want to broaden their perspective while at the same time maintaining a strong focus on practical relevance for engineering education.

We warmly invite you to read specific chapters based on your own interests or questions that may arise from your teaching context, your educational practice, your engineering field, your institutional setting, or the particular skill or competency you wish to integrate into your teaching. As noted earlier, there may be overlapping areas or shared dimensions between some of the competencies and skills. In such cases, it can be helpful to read and connect two or more chapters, especially where they complement one another or address similar aspects from different angles. Common to each of these chapters is that they contribute to a better understanding of the respective competency or skill. They offer practical insights, useful contextual information, and implementation strategies at the module level.

3 Transferable competencies and skills covered in Part 2

All chapters in Part 2, each focusing on an individual competency or skill, are derived from the three themes described in detail in Chapter 1.5. Each theme brings together a set of competencies and skills that are thematically aligned, thus shaping the overall structure of this part of the handbook. This introductory chapter (2.1) is followed by Chapter 2.2, which marks the beginning of the competency- and skill-focused contributions.

The first theme, *Responsibility, Project Management, and Leadership*, spans Chapters 2.2 to 2.6. In Chapter 2.2, Faith Nightingale and Raffaella Manzini present a process-oriented approach to project management. Chapter 2.3 by Ryan Grammenos and Jevgenija Prisutova explores effective meeting practices. Claire Lucas and Diana Martin examine risk management in Chapter 2.4. Chapter 2.5, on leadership skills, is contributed by Ewa Marjańska, Cindy Rottmann, Meagan Kendall and Anna Maria Trzaskowska.

The second theme, *Communication and Interpersonal Skills*, in Chapters 2.6 to 2.12, focuses on expression and collaboration. Chapter 2.6 by Éva Kalmár, Siqing Wei, Yousef Jalali, and Homero Murzi covers teamwork, while Chapter 2.7 by Patrick van Delft and Martijn Wackers and Chapter 2.8 by Oscar van Putten and Angeniet Kam explore oral and written reporting. Visualisation is the focus of Chapter 2.9 by Nathalie Al Kakoun, Rehan Shah, and Ilanthiraiyan Sivagnanamoorthy. Chapter 2.10 by Vladislav Krivoshchekov, Ina Peters, Sabine Ammon, and Siara Isaac addresses interpersonal communication, followed by feedback-focused Chapters 2.11 by Leah Ridgway, Aled Davies, Greg McNamara, Brendan Hayes, and Ceri Morris, who discuss feedback and 2.12 by Alexandra Werth, Stephanie Fuchs, Jonathan Butcher, and Jennifer Meyer who discuss feedback literacy.

The third theme, *Professional Commitment and Lifelong Learning*, in Chapters 2.13 to 2.19, covers metacognition, adaptability, resilience, information literacy, motivation, and perseverance. Chapter 2.13 on self-regulation is by Shan Tuyaeerts, Lynn Van den Broeck, Vicent Rutagangibwa, Peter Ruijten-Dodoiu, and Tinne De Laet. In Chapter 2.14, Samantha Brunhaver discusses adaptability and change management. Chapter 2.15 explores resilience and is authored by Natalie Wint, Stephanie Lunn, Inês Direito, and Curwyn Mapaling. Chapter 2.16, authored by Natalie Wint, William Bennett, Deborah Bauder, Cristina Tripon, and Freeha Azmat, and focuses on information literacy. Chapter 2.17 on autonomous motivation and learning beliefs is by Dan Jiang, Olga Pierrakos, and Nathalie Al Kakoun, while Chapter 2.18 on initiative and perseverance is authored by AraOluwa Adaramola, Nathalie Al Kakoun, and Alexandra Werth.

The editorial team of this handbook's Part 2 will conclude Part 2 in Chapter 2.19, offering a reflection on the themes presented and exploring tools for critical reflection and integrative learning.

4 Aligning transferable competencies and skills with assessment and evaluation

Just as Part 2 builds directly on Part 1, it also sits within the broader structure of the handbook. The themes and chapters introduced here connect to Part 3, which focuses on assessing transferable competencies and skills. It also connects forward to Part 4, which highlights how the core of engineering curricula supports transferable competencies and skills, and finally to Part 5, which addresses how to evaluate needs, interventions, and outcomes related to teaching transferable competencies and skills.

We cannot stress enough that transferable competencies and skills can only be effectively taught and developed with students if they are properly aligned with and clearly connected to appropriate learning outcomes (as the starting point), as well as to suitable forms of assessment (Biggs & Tang, 2011). That makes Part 3 on assessment particularly significant for transferable competency-oriented engineering education practice.

With that in mind, we strongly encourage you to engage attentively with Part 3 of this handbook, as it offers support in identifying relevant assessment forms and formats for competence-based teaching practice. These can be further complemented by Part 5, which focuses on evaluating educational needs, interventions, and outcomes. Meanwhile, Part 4 may serve as a valuable source of inspiration, showcasing examples of systematic integration of transferable competencies and skills on a programme level. This may be especially helpful for those interested in organisational development and broader institutional strategies. It highlights case studies that can guide and inform your own practice.

5 Call to action: Get going and learn together (with your students)

Like the rest of the handbook, each chapter in Part 2 has been written to be read independently. However, these contributions are most effective when you use them as a toolkit rather than just reading material. Whether you are designing a brand-new module, tweaking a current one, or just looking for a fresh perspective, these chapters are here to support your specific goals. They are written for you, the practitioner, to help you not only understand these competencies and skills, but to embed them into the engineering classroom in a way that works for you and your students alike.

We suggest treating these competencies and skills just like an engineering problem: prototype, experiment, and iterate. There is no single *right way* to teach transferable competencies and skills, and successful competence and skill development will depend entirely on your approach, your students, and the setting you are in. Do not be afraid to try something that might not work perfectly the first time. In fact, by showing students that you are refining your methods based on feedback, you model the very adaptability and resilience this handbook champions.

Also, moving toward competence-based teaching does not mean tearing down your curriculum to start from scratch. You likely foster many of these competencies and skills already, perhaps without naming them. This handbook can simply help you make

those implicit habits explicit. Articulating what is already there validates your current practice and makes the learning path much clearer for your students, often without adding a heavy workload.

Reflective practice like this brings your hidden assumptions to the surface, making them easier to discuss and share with colleagues. We hope the evidence and examples in this handbook prove useful in your own context. Remember, there is no one-size-fits-all approach! Instead, we invite you to take these ideas, adapt them, and make them your own. We believe this handbook is a rich resource, and we strongly encourage you to draw inspiration from it and try any and all strategies, methods, and tools in your engineering education practice. Feel free to share your experience; we would love to hear from you.

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AI statement

During the preparation of this work, the authors used ChatGPT (OpenAI) for proofreading and editorial support (e.g., grammar, clarity, and concision). After using this tool, the authors reviewed, edited, and adapted the content as needed. They take full responsibility for the content of the publication.

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2.2

Process Management on a Process Level

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Keywords: *project management, employability, engineering education, project-based learning*

Project management is a key engineering skill, which encompasses several technical and transferable skills and competencies, necessary to ensure the successful completion of complex engineering projects. In this chapter, a definition and a brief history of project management is provided, and some reflections on its importance for engineers are offered. Then, a practical example is described that shows how to help students to develop the set of skills embedded in project management: a programme designed within a Joint Education Institute by Queen Mary University of London Engineering School at Northwestern Polytechnical University in Xi'an, China. Students at this university undertake Professional Engineering Skills (PES) modules during the first three years of study, which are designed to support students to develop academic, professional, and employability skills. The example shows the importance of a progressive and developmental approach to project management to ensure student success. Finally, the chapter discusses some considerations and lessons learned about teaching project management to engineers.

1 Definition

The work of engineers is increasingly described and organised in terms of “projects”, whatever their specialisation: goal orientation, problem solving, and time and resource constraints characterise engineering activities. That is why project management has become such an important discipline for engineers.

Defining project management implies, first, the definition of what a project is. Many definitions of a project can be appropriate, depending on the perspective and reference context (Bredillet, 2007; 2008; Kolliveit et al., 2007):

- Planning perspective: the project as a set of activities to be completed within a certain time, with a defined number of resources;
- Organisational perspective: the project as a set of resources that need to be organised to realise the project’s objectives;
- System perspective: the project as a set of sub-systems, dynamically interacting with each other, letting problems, conflicts and solutions emerge from that interaction.

A possible integrated definition, which considers all the perspectives above, could see the project as a process in which human, material and financial resources are organised in a new way to achieve a unique output within defined time and cost constraints (Buganza & Kalchschmidt, 2022; Turner, 1999).

Managing projects is not trivial, as has been known since ancient times. An excellent example is Vitruvius’ work *On Architecture*, dating to the first century BCE, which describes in detail the technical and organisational aspects in the construction of aqueducts. But it was only in the 20th century that project management moved beyond the ‘artisanal’ dimension and became a technical discipline, with a solid theoretical background complementing the practical experience. Henry Gantt was probably one of the first authors designing tools for supporting the organisation and management of engineering projects. Following Gantt and the world-famous Gantt Chart, several other authors in the first half of the 20th century developed tools such as the Critical Path Method (CPM) and the Program Evaluation Review Technique (PERT) for scheduling activities. Since then, project management has been conceived mainly as a discipline focused on planning activities and plan optimisation. Later in the 20th century, aspects more related to project organisation, costs, and expected revenues have been considered, for example in the Work Breakdown Structure for eliciting the activities necessary to achieve the project scope, and the Earned Value techniques, for measuring the economic impact.

In 1969 an important organisation was established, the Project Management Institute (PMI), a community working to support managers in developing, improving, and sharing tools for increasing the probability of projects success. With the establishment and the growth of the PMI, project management has been recognised as a discipline, and the project manager established as a professional role. Since then, the discipline

has continuously evolved, increasingly including more 'soft' aspects concerning the cultural, human, and social side of project management. The aspect of the *impact* generated by engineering projects has also emerged as fundamental: the PMI's current vision is indeed building "*a world where every project lives up to its full potential for positive impact*" (PMI, 2026, front matter). Project management has thus become a discipline which is aimed not only at ensuring the project's success but also making sure that projects generate economic and social value.

Following the Project Management Book of Knowledge (PMBok) published by the PMI we use the following definition of project management: "*the application of knowledge, skills, tools and techniques to project activities to meet the project requirements*" (PMI, 2026, p. 4). The PMBoK illustrates and discusses the most important technical tools for project management and their application in various contexts. But human skills and competencies have a dramatic impact on the success of projects (Rezvani et al., 2018; Pant & Barouni, 2008; Stevenson & Starweather, 2010). Among them are social skills — defined as "*a person's ability to understand, socially interact, control, read effectively to fulfil an objective or a specific goal*" (Zaman et al., 2019, p. 446) — , communication skills, teamwork, leadership, adaptability, and verbal and written reporting skills. So, being good project manager is a matter of integrating technical skills with human and social skills. Not an easy task, but one of which you should be fully aware.

2 Why teach project management?

It is widely recognised that engineering work is predominantly organised through projects. Consequently, the ability to manage projects successfully is crucial for engineers. Engineers are required to have a number of technical skills, as well as transferable skills and competencies to be considered competent in their profession (Engineering Council, 2020). However, it is widely reported that engineers lack transferable skills and competencies. The Employer Skills Survey cites that 51% of engineers lack time management and task prioritisation skills (Winterbotham et al., 2018), even though these are key skills in project management. In the end, this has a negative effect on the profit of businesses (IET, 2021). The same is indicated by accreditation bodies and frameworks, such as the UK AHEP4 and the related EUR-ACE Accord (EUR-ACE), Washington Accord (WA), Sydney Accord (SA), and Dublin Accord (DA). Indeed, they explicitly mention engineering and project management among the areas of learning that are expected from bachelor- and master-level engineers. The Global Competitiveness Report 2020 (WEF, 2020) discusses the need for educators to ensure students leave education with 'job-ready skills' for the future job markets, especially for recovery after the COVID-19 pandemic. Therefore, it is a university's responsibility to ensure students develop the skills needed during their studies (Department of Education, 2017) in an inclusive manner, using innovative pedagogies. Additionally, for engineering education institutions to be accredited, the capacity to bring into their regular curricula all the necessary transferable skills and

competencies to make engineers successful including the ability to apply the principles of project management is key.

Moreover, successful project management is becoming increasingly challenging due to budget constraints, time pressures, and rising levels of risk and cost (Stevenson & Starkweather, 2010). This underscores the need for engineers, and, more importantly, for engineering educators, to integrate the necessary skills and competencies that enhance the probability of project success into the curriculum. We cannot expect that students are able to perform at the level of a project manager, especially at a first-year undergraduate level, so project management should be taught in a progressive manner.

2.1 Intrinsic characteristics of engineering projects

But why is managing such projects so difficult? The discipline of project management can be described as “*a multifaceted discipline that involves planning, executing and completing projects of all sizes and complexities*” (APMG International, 2023). The increasing complexity of project management stems from a range of factors, some intrinsic to the nature of projects, others related to the broader contextual environment in which these projects take place. The following characteristics, inherent to engineering projects, contribute to their complexity:

- *Uniqueness of outputs and activities.* Each project typically delivers a unique output through non-standardised activities, limiting the applicability of established processes, routines, and procedures;
- *Temporary nature.* Projects have defined start and end dates, requiring the creation of a dedicated temporary organisational structure with appropriate allocation of resources and competences;
- *Need for new competencies.* Achieving novel or innovative outputs may demand skills that are not readily available within the organisation and must therefore be acquired externally or developed internally;
- *High interdependence.* Projects often involve complex interrelations between their various components, requiring integrated planning and coordination;
- *Goal orientation.* Specific project goals need to be identified and codified, requiring iterative definition and alignment within the organisation.

2.2 Contextual complexity

Beyond their intrinsic features, engineering projects operate in increasingly dynamic technological, social, and economic environments. Today’s projects frequently involve multiple and diverse stakeholders or ‘agents’, including large and small enterprises, universities and research institutions, government bodies, communities, end users, and even physical ecosystems. These agents have dynamic interactions among them, often in unpredictable ways, contributing to emergent behaviours and outcomes that cannot be easily foreseen or controlled.

As a result, project management is characterised by high levels of uncertainty, risk, and organisational and managerial complexity. In light of these challenges, the literature increasingly recognises that successful project management requires a broad and integrated set of skills, competences, and tools. These include a mix of technical, interpersonal, professional, and transversal skills, many of which are explored in other sections of this handbook and are consistently emphasised in both academic and professional sources. As highlighted by the Royal Academy of Engineering (2024) in its Engineering 2030 literature review: *“Although working with problems, creativity, and systems thinking can all be defined as individual skillsets, the way these skills come together often works as a skillset in its own right, especially when combined with project management skills. The primary examples of this are in optimisation and innovation, and the combined skillsets needed are becoming ever more prominent as technologies become more interconnected and complex”*.

Historically, project management education and practice focused predominantly on the “hard” side - the technical tools and methods at the core of the discipline. The Project Management Institute and its foundational Project Management Book of Knowledge (PMBok) offer key references in this domain, particularly concerning technical tools and best practices validated through extensive professional application. However, recent contributions from both the scientific (Buganza et al., 2013; Pant & Baroudi, 2018; Rezvani et al., 2018; Stevenson & Starkweather, 2010; Zaman et al., 2019) and professional (RAE, 2024) communities underscore that technical skills alone are insufficient for project success.

Stevenson and Starkweather (2010), for example, identified critical project management competences in IT projects, including leadership, multi-level communication, verbal and written reporting skills, a positive attitude, and the ability to manage ambiguity and change. Similarly, Belzer (2011) referred to soft skills as the ‘missing link’ for successful project outcomes, emphasising competences such as communication, organisational effectiveness, leadership, problem solving, decision making, team building, flexibility, creativity, and trustworthiness. The literature increasingly emphasises that project managers must achieve project objectives through people, managing not only tasks and technical aspects but also the human, psychological, and social dimensions of project work. These dimensions are no less critical than technical proficiency to ensuring successful project completion. Therefore, there is now a broad consensus among scholars and practitioners on the necessity of integrating technical and socio-human skills in project management. This awareness must be followed by a second, equally essential step: understanding how such an integrated skill set can be effectively taught within traditional engineering curricula.

3 Forms of implementation

This section will identify a case study where project management has been implemented to develop the transferable skills and competencies of students at undergraduate level over the duration of the degree programme.

Context

Queen Mary University of London Engineering School at Northwestern Polytechnical University, in Xi'an, China, offer a Joint Education Institute (JEI) for two undergraduate programmes of study: Material Science and Engineering and Polymer Material Science and Engineering. The programme of study spans four academic years, after which students are awarded a degree from both universities.

During the first three years of study students undertake Professional Engineering Skills (PES) modules which are designed to support students to develop academic, professional, and employability skills. Each year has around 240 students in two classes of approximately 120 students each.

Level of study and progression

Fig. 2.2.1 below shows the main professional skills that we address in each of the modules throughout the programme of study.

Year 1- Academic and PES	Year 2- Developing PES	Year 3- Business and PES
• Time management • Lecture comprehension • Technology • Teamwork • Critical thinking and reflection • Engineering logbook • Safety and risk assessment • Employability	• Innovation and creativity • Problem solving • Sustainability • Pitching ideas • Poster presentations • Engineering logbook • Safety and risk assessment • Employability	• CPD • Ethics • IP, patents, law • Quality management • Project management • Engineering logbook • Safety and risk assessment • Employability

*Figure 2.2.1: Professional Engineering Skills (PES) modules outline
(Own Work by Faith Nightingale)*

In PES1, we introduce time management and teamwork as key skills that form part of project management in terms of time and resource management. In PES2, the project-based approach introduces more developed teamwork skills and skills such as recording meeting minutes as part of student project management development. Finally, in PES3, project management is introduced at a higher level through guest lectures and use of project management tools and modules. It is vital that learning project management skills is scaffolded because there are many skills that need to be developed within project management, such as time management, teamwork, and planning and organisational skills. Additionally, context plays an important role in the scaffolding of skills. This case study shows that especially for undergraduate students

who may be unaware of project management, in this transnational setting, with two countries where the pedagogy and culture are different, scaffolding is essential.

Teaching methods

To teach project management, an interdisciplinary, project-based approach needs to be used, with real-life engineering scenarios. This method aligns with the growing emphasis in engineering education on problem and project-based learning (PjBL) as a means to prepare graduates for complex, real-world challenges (Kolmos et al., 2023; Lavado-Anguera et al., 2024). Interdisciplinary PjBL enables students to work across technical and non-technical domains, reflecting the collaborative nature of modern engineering projects. By simulating authentic engineering contexts, students engage in experiential learning that fosters critical thinking, systems thinking, and adaptability (Lavado-Anguera et al., 2024). This also aligns with the development of skills which are valued by professional engineering institutions. Lavado-Anguera et al. also note that PjBL enhances both technical competencies and transferable skills such as leadership, negotiation, and conflict resolution. By enhancing transferable skills and competencies in a real-world project using hard skills, students will develop interdisciplinary abilities and project planning and execution abilities, meeting industry demands.

There is also an opportunity to further innovate and develop additional skills, particularly technological skills. Traditional teaching methods such as lectures, case studies, and hands-on workshops remain valuable for building foundational knowledge and structured problem-solving habits. These approaches provide the conceptual grounding necessary for understanding project management frameworks. However, integrating innovative, technology-enhanced methods can significantly expand skill development. For example, collaborative platforms like Office 365 facilitate real-time teamwork across geographies, reflecting the distributed nature of modern engineering teams, even if, as in this context, the students are in the same location. It helps them develop skills for the future and use technology in case they cannot meet in person due to other commitments. Importantly, digital literacy is essential in project management. Therefore, balancing traditional and innovative pedagogical methods ensures that students not only master established project management practices, but also adapt to emerging technologies, preparing them for leadership in a rapidly evolving professional landscape (Falasi, 2024).

Practical examples

Example 1. Implementing project management skills in a programme

Year 1.

As part of a joint assessment with an English module, project management is not explicitly taught, but the skills teamwork and time management are introduced and practiced so that students are able to use key elements of project management.

For the assessment, groups of five or six students are asked to prepare a short presentation and lead a seminar on an engineering topic. Students are given several

weeks to prepare for this and are also supported with other skills such as presentation and seminar participation skills. However, project management is used in the form of writing action plans, as seen in Fig. 2.2.2.

Action Plan 1

Date:

Person responsible Who is doing the task?	Task Provide clear details about the task each member needs to do, including specific requirements, resources, or steps needed to complete the task.	Submission form E.g. word doc, PPT, URL, image, excel figure etc. on SharePoint	DDL Date the task should be finished.	Task comp'd? Not Started/ In Progress/ Completed	Checker Who is checking the task?	Comments on the work 2 positives, 2 improvements from checker

*Figure 2.2.2: Action plan — Year 1 project management
(Own Work by Faith Nightingale)*

The action plan aids students in developing their project management skills by organising people, tasks, resources, and time, as shown in the first five columns of the table. The title of each column also includes an explanation of what information should be included, which is important to ensure that first-year students understand the requirements.

It also acts as a feedback mechanism to aid students in the development of their work. Feedback is given internally by other group members, as someone is assigned to check the work and give comments, as seen in the final two columns of the table. Giving and receiving feedback develops students' professional skills as well as replicating real-life scenarios, e.g., receiving and acting on feedback from a teacher, or in the workplace, a manager.

The action plan is assessed as part of the group project in order to assess the skills and engagement of the students. The number of action plans, use of technology, communication skills, and responsibility are all taken into account. At the JEI, students value grades highly, which is why it is important to assess these skills in a quantitative way. However, students also complete their Engineering Logbook as a way to show their professional development (Nightingale, 2022), which enables students to reflect on their performance and therefore aids in the development loop of gaining professional skills.

Year 2.

In order to develop the professional engineering skills of students, the module is completely project-based. Students complete two projects, one per semester, which are focussed on real-life engineering scenarios.

In the first semester, students complete a joint assessment in Engineering Design Methods and Developing Professional Engineering Skills. The project aims to enable students to use their creativity and innovation skills to design their own product

using features of sustainability, CAD/CAM, and market research. As an interdisciplinary, semester-long group project, project management is key to ensure the smooth running of this project.

To develop the project management skills from Year 1, students in Year 2 are required to record meeting minutes in addition to developing and following up on the action plan. Students are asked to create written minutes of the meeting and upload them to SharePoint after each meeting (which also improves their technology and software skills). Guidance in class is given via a 'meeting minutes' guide. One of the reasons for requiring students to record meeting minutes is to develop workplace skills in three areas. Firstly, arranging a meeting can be difficult for the students because of their busy timetables and the fact it is group work. Therefore, not all students are available for every meeting, so having minutes enables those who missed the meeting to catch up on what was discussed and the tasks that were decided upon.

Project Management Form Template				
Your group number				
Attendance (Indicate Chair & minute taker)				
Absence				
Project and meeting number				
Date, time and place of meeting				
Discussion point/task				
Action Plan				
Member	Detailed action points	Submission form	DDL	Task comp'd?

*Figure 2.2.3: Project management meeting minutes
(Own Work by Faith Nightingale)*

Secondly, recording the assigned tasks creates accountability for the students, which is considered when reviewing the meeting minutes. It is expected that all students contribute to the project during each phase, including the meetings, so recording discussions as well as tasks is important since this ensures that each person is aware of their responsibilities and deadlines, enhancing accountability. Project engagement is also part of the marking criteria, so it is expected that each person's contribution can be tracked throughout the project. Thirdly, by being the minute taker, professional skills such as listening and communication, assertiveness, organisation, reporting skills, and critical thinking skills are developed (Lee, 2025). At the JEI, the students are expected to rotate roles, so they are able to develop a

variety of skills throughout the project. It is also important to develop all of these areas, as these are all professional skills that students will need in the future. Fig. 2.2.3 shows the meeting minutes template.

One point to notice is that the feedback loop is not included in the action plan at this time. This is because it is expected that students will continue this feedback loop themselves and discuss it in the meeting itself (as a developmental factor from Year 1). Additionally, the meeting minutes are commented on by the teacher to add another layer to the feedback loop, namely, to see if the documents are readable from an outside perspective. This is important to help the students develop the transferable skills and competencies mentioned above when learning to take meeting minutes. The project management documents are commented on during the project to enable the students to continuously develop throughout the project and are evaluated at the end. Overall, research carried out at the JEI showed that 66% of students said they developed their project management skills significantly during the project.

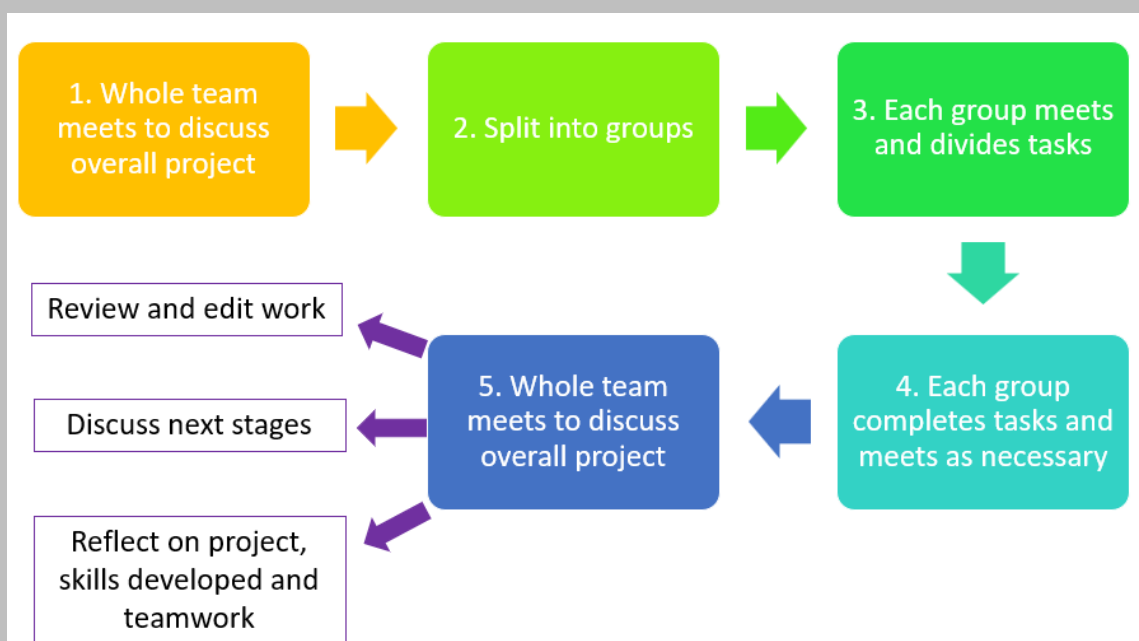


Figure 2.2.4: Project management process - team division
(Own Work by Faith Nightingale)

In the second semester, project management skills are further challenged and developed during the Materials Library project. The aim of the project is to create a database of materials or components which can be touched (where appropriate) and accessed through a website. This is done in three stages: creating a poster, creating a website, and giving a presentation. The poster is completed in pairs, and a competition is held where student peers assess the posters to choose the winners. Once the winners are chosen, large groups of eight or nine students are formed via a recruitment fair. As this is the first time that students work together in such a large group, project management is developed in two ways. Firstly, students are

advised to divide the large groups into smaller sub-groups. It is then recommended to assign a sub-team leader (usually one of the poster pair). Teamwork and leadership skills are discussed in class, and students are encouraged to follow Fig. 2.2.4, which shows the project management process in simple, easy to follow steps. This is done as students are not used to working in sub-teams, so guidance is essential. This also enables students to see stage 2 of the project overall and how to move into stage 3. During this process, students are required to still write meeting minutes each time the whole group or the sub-group meets to show the development of the Materials Library project and add these to their SharePoint group (continuing to develop the technology skills from Year 1).

The second way in which students develop their project management skills in this project is by completing a Gantt chart to aid in the planning of the project overall and the academic skills required for it, such as researching, writing, and editing. A Gantt chart is useful as it enables the entire group to see the project as a whole and understand the process of the project and the actual complexities. It also helps students set a timeframe to complete each task, as well as understand that actions can overlap. This will aid students as they aim to complete larger projects in the future, such as their final year dissertation projects.

One final step which is not directly related to project management, but an important step towards developing the skill is reflection. By reflecting on the project as well as some of the tools used in the project, they can develop this skill. For example, reflecting on the time given to each task on the Gantt chart can help students identify if they were realistic or not, and therefore, develop knowledge of timeframes and being realistic when it comes to task completion.

Year 3.

In the final year of the professional skills modules, students are expected to keep using the project management skills and tools they have developed in the first two years to complete the projects in the third.

However, in order to prepare students for the workplace and to give them an understanding of how project management is used by engineers, a guest lecturer gives the students a talk about real-world industry project management. Attending a talk by an industry professional enables the students to understand how these skills fit into their future engineering careers.

Students are also given the opportunity to use online resources from PMBoK to develop key project management understanding by looking up information on the subject, such as the project lifecycle, phases, and importantly, what is a project. This deeper understanding of project management enables students to understand when they can use the project management skills they have been developing over the past years. Students are also guided towards their final year projects by discussing leadership, communication and scheduling; all key project management skills which are needed by students as they aim to complete their degree programmes.

Challenges and solutions

The main challenge when teaching project management in engineering education is helping students to understand the importance of project management. It is difficult for students to understand that project management is a skill and combines several other professional skills to be successful. Whilst students understand the main theory behind project management, implementing it using a variety of other professional skills can be difficult. For example, communication and teamwork are skills that can be developed.

To solve this, it is important to develop students' communication and teamwork skills. This can be done as part of project-based learning, using the project management tools described above. It is also important to explain project management in an engineering context through AHEP4 and its use in professional institutions and in the workplace. Reflection on the development of project management skills after the project will also help students understand the importance of project management.

4 Recommendations for implementation and learning

Project management skills must be developed in a process that spans the entire engineering programme. As part of this progressive approach, students should first develop an awareness of the need to develop specific skills to successfully manage a project. It is necessary to gain direct experience of the complexity of engineering projects, which in turn allows students to fully appreciate the value of project management support tools. Once this awareness has been developed, students are ready to begin learning how to apply the tools, starting with the simplest ones, such as the action plan and the Gantt chart. At the end of the process, students should be given the opportunity to experiment with integrating 'hard' project management tools (action plans, Gantt charts, CPM, etc.) with other professional skills, such as communication and team management, leadership, and problem solving.

A second key recommendation is that in order to develop project management skills, these must be taught using project-based learning pedagogy. PjBL is key to putting the skill into context; teaching project management in isolation is not going to develop the skill, as students will have no place to practice it. What is important, however, is that project management skills need to be taught as part of the pedagogy. It is impossible for this skill to be developed without explicit teaching, as project management combines skills such as time management, teamwork and communication skills. Therefore, it is essential you give lessons on these skills, as well as opportunities to practice these skills.

These recommendations lead us directly to the lessons we have learned from teaching project management to engineers. Teaching project management means helping students develop many professional skills related to communication, leadership, problem solving, and managing teams (and, therefore, diversity and inclusivity, time management, and conflict resolution. This is why teaching project management is so complex and requires a progressive approach. This means that the activities (projects)

you choose to teach project management to engineers should last at least five to six weeks, to give students the opportunity to really build up their skills, both technical and professional. Projects should be open-ended and include some risks and uncertainties in order to force students to generate, evaluate, and manage multiple alternative options. This is essential for exploring and fully exploiting the potential of technical project management tools and professional skills.

The use of project management as part of skills development is highly adaptable to any context, but you need to consider two main factors: stage of the degree and culture. It is vital you consider the degree stage to ensure that the set project management skills are reachable for students. This is why project management needs to be developmental throughout the curriculum. Culture is another consideration, as the content needs to be relevant to the students and should also give room to experiment with the value of different technical or social student backgrounds.

Adaptability means that introducing project management skills in engineering curricula cannot be completely standardised, as it should be tailored according to the background knowledge of students and their cultural and social characteristics. This allows for reflecting on the value of diversity for project management and how it influences the success of projects. As shown in the practical examples at the JEI, project management can be taught to large classes (120 students), as long as an appropriate active pedagogy is used. Therefore, you can adapt the ideas above to smaller class sizes. This may yield better results, as the instructor will have more time to spend with smaller groups, and thus can ensure they are writing minutes accurately or develop an accurate Gantt chart.

Avoiding standard approaches is also consistent from the students' perspective. As already mentioned in this chapter, it is sometimes difficult to convince students of the relevance and importance of project management skills, compared to the technical skills that form the core of their engineering programme. In our experience, they can only be profitably engaged with learning project management skills if these are strongly integrated into the fundamental technical skills, which remain their focus. At the JEI, research has been conducted into the effect of teaching professional skills; one key comment from students is that project management helped them when devising and executing their final year dissertation projects. This is because this required all the professional skills they had previously learned, with a high emphasis on time and project management skills.

One way to improve the project management skills of the students is to try different project management tools, as mentioned at the beginning of this chapter. Instead of just using a Gantt chart, more emphasis could be placed on developing students' knowledge of Critical Path Analysis or Program Evaluation Review Technique. This would enable students to choose which tool to use in a particular situation, thus also aiding the students' reflection and self-development skills.

The main takeaway about project management skills is their applicability to all kinds of disciplines and contexts. One of the most surprising results for teachers is hearing students say, *'I can use these tools in my personal life too'*. This should offer motivation for us to start teaching project management skills.

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AI statement

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2.3

Meeting Skills in Engineering Education: Practical Strategies for their Effective Development

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Meetings are core mechanisms through which engineers coordinate complex technical work, make decisions, review designs, manage risk, and collaborate with diverse stakeholders. Yet, meeting skills are rarely taught explicitly in engineering programmes, despite strong evidence that structured facilitation, inclusive participation, and effective documentation significantly improve both team performance and project outcomes. This chapter provides you with a practical, research-informed framework for embedding meeting skills into curricula through scaffolded learning, authentic engineering scenarios, and progressive independence. Drawing on professional standards and empirical studies across engineering institutions, we define meeting skills as a set of transferable competencies that include preparation, facilitation, communication, decision making, and follow-up. The chapter offers concrete examples, implementation strategies, and recommendations based on practitioner experience, enabling you to support your students in developing meeting practices that mirror real engineering environments. Ultimately, meeting skills strengthen technical coordination, foster inclusive team cultures, and prepare graduates for the communication demands of modern engineering practice.

1 Definition: essence of the skill

1.1 Concept: defining meetings and meeting skills

A *meeting* in engineering is a structured, purposeful interaction where participants exchange information, coordinate technical work, evaluate options, or make decisions necessary for progressing a project. Unlike general business meetings, engineering meetings frequently involve complex technical content, structured review processes, multidisciplinary collaboration, regulatory considerations, and high-stakes decision making.

The term *meeting* originates from the Old English *metan*, meaning ‘to come together’, but its modern engineering interpretation reflects much more: meetings are formal coordination mechanisms central to design reviews, project planning, risk assessments, client consultations, sprint reviews, safety briefings, and cross functional decision processes (ASME, 2018; NASA, 2018).

Meeting skills therefore refer to a set of teachable professional competencies that enable engineers to prepare for, participate in, lead, and follow up on meetings effectively. These skills extend beyond generic communication abilities, encompassing technical precision, facilitation strategies, structured decision making, documentation standards, and inclusive participation practices tailored to engineering environments (Changpueng & Pattanapichet, 2024; Galster et al., 2024).

Professional bodies, such as the UK Engineering Council and the Institution of Engineering and Technology (IET) explicitly list meeting competencies, such as contributing to, chairing, and recording meetings, as evidence of communication, leadership, and interpersonal skills expected of engineering professionals (Engineering Council, 2020; IET, 2015). Meeting skills are therefore not informal behaviours but essential elements of engineering competence that influence project quality, team performance, safety, and stakeholder relationships.

1.2 Theoretical framework: foundations for meeting competence

Professional engineering frameworks consistently position meeting skills as integral to broader communication, teamwork, and leadership competencies.

- In the United Kingdom, the UK Standard for Professional Engineering Competence (UK-SPEC) requires engineers to “*contribute to, chair and record meetings and discussions*” as evidence of effective communication and interpersonal skills.
- In the United States, the Accreditation Board for Engineering and Technology (ABET) requires graduates to communicate with diverse audiences and function effectively in teams that establish goals, plan tasks, and meet objectives (ABET, 2024).
- In Europe, the European Network for Accreditation of Engineering Education (ENAAE) frames outcomes for the EUR-ACE label that include communication, teamwork, and use of virtual communication tools (ENAAE, 2021). Engineers

Europe highlights teamwork, leadership, and communication for the EURING professional title.

- The International Council on Systems Engineering (INCOSE) competency framework specifies planning, logistics, style selection, and goal clarification as core abilities for facilitation in technical contexts (INCOSE, 2018).
- The Conceive-Design-Implement-Operate (CDIO) framework embeds communication and meeting-related skills through integrated curricula and design build projects (CDIO, n.d.).

Together, these frameworks position meeting skills as structured, assessable competencies rather than incidental behaviours.

1.3 Key components: core skills for engineering meetings

The following components reflect how meeting skills manifest across preparation, facilitation, communication, decision making, and follow-up in engineering settings.

- *Preparation and agenda design.* Define clear objectives, select participants, structure time-bound agendas, circulate materials in advance, and prepare technical inputs (e.g., design documents, risk logs, specifications). Systems engineering practice underscores rigorous preparation before design and compliance reviews (INCOSE, 2018; NASA, 2018).
- *Facilitation and meeting leadership.* Guide technical discussion, maintain focus on engineering objectives, moderate multidisciplinary viewpoints, manage time and transitions (Engineering Council, 2020; IET, 2015).
- *Clear, inclusive, and accessible communication.* Use active listening, invite balanced participation, clarify assumptions, adapt explanations to both technical and non-technical audiences, and plan for accessibility (Cha et al., 2024; Kimpton & Maynard, 2023).
- *Collaborative decision making and technical problem solving.* Synthesise evidence, weigh trade-offs, use explicit decision rules, and confirm shared understanding. Studies show that structured agendas, role clarity, and time allocation improve information sharing and coordination in engineering teams (Galster et al., 2024; Luchini et al., 2021; Selinger, 2010).
- *Documentation and follow-up.* Capture accurate meeting minutes delineating the decisions and actions with owners and deadlines; circulate summaries and track progress for traceability and assurance. This is critical in engineering for compliance and auditability (NASA, 2018). Structured documentation also supports reflection and improved meeting effectiveness in educational contexts (Leandro Cruz et al., 2022).

These components collectively form a practical, teachable competency framework that aligns with professional standards and matches the detailed implementation strategies described later in this chapter.

1.4 Contextual variations: how meeting skills manifest across different engineering settings

Meeting skills manifest differently across distinct engineering contexts:

- Educational settings emphasise scaffolded practice, role rotation, and formative feedback (Kimpton & Maynard, 2023; Leandro Cruz et al., 2022);
- Industrial environments and professional settings require higher-stakes coordination, formal documentation, and multi-stakeholder participation. Technical review meetings (e.g., design reviews, risk analyses) require precision, evidence-based argumentation, and rigorous decision processes (ASME, 2018; NASA, 2018);
- Multidisciplinary and client or regulatory meetings involve communication across disciplines, each with distinct technical vocabularies and priorities, which require clarity, structured presentation of evidence, and awareness of compliance requirements (Misnevs & Demiray, 2017).

Despite these variations, the core skills remain consistent; only the complexity, stakes, and formality change.

2 Why teach meeting skills?

In this section, we look at why structured meeting skills are foundational to professional engineering. Drawing on literature, industry standards, and educational data, we show that structured meeting practices directly support coordination, decision making, and project success.

2.1 Empirical evidence: why meeting skills matter in engineering contexts

Research demonstrates why meeting skills deserve explicit attention in engineering education. Engineers spend up to 57% of their working time in active communication, including meetings (Leandro Cruz et al., 2022), making meeting competence essential for daily professional effectiveness. This time investment encompasses diverse meeting contexts, including formal design reviews at key stages of product development, information-gathering meetings with stakeholders and domain experts, and recurring coordination rituals like daily stand-up meetings in agile software teams (Huet et al., 2007; Loweth et al., 2021; Stray et al., 2016). These meetings serve as central venues for evaluating engineering work, sharing knowledge and rationale, and making technical design decisions.

Career progression research reveals that while technical expertise may secure initial employment, interpersonal deficiencies, including poor communication and meeting skills, are primary reasons for career setbacks, whereas leadership and collaborative abilities drive advancement (Russell & Yao, 1997). Conversely, research shows that miscommunication represents a leading cause of project issues, with Misnevs and Demiray (2017) finding that effective communication among project team members is one of the most important factors in minimising project failure. Well-defined meeting processes, including clear agendas, precise role assignments, and comprehensive documentation, improve both efficiency and final product quality, while poor communication leads to misinterpretation, inefficiency, and time wastage (Habra, 1997; Keane & Gibson, 1999).

There is also a well-documented skills gap. Only 35% of employers believe new engineering graduates are adequately prepared in regard to communication and teamwork, while 74% of education providers think they are successfully equipping students (Craps et al., 2017). This discrepancy reveals not only a skills gap but a significant perception gap about the adequacy of current educational approaches.

In software engineering and other multidisciplinary teams, research has shown that specific meeting behaviours, including active listening, accurate communication, and structured turn-taking, directly improve information sharing and coordination (Galster et al., 2024). These findings collectively show that meeting skills, which act as core enablers of effective engineering practice, are learnable behaviours.

2.2 Importance for engineers

Engineers routinely participate in meetings such as design reviews, risk assessments, requirements clarification sessions, sprint reviews, safety briefings, and multidisciplinary coordination meetings. These meetings require clarity, precision, and structured facilitation to ensure team members share a common understanding of objectives, constraints, and technical decisions (NASA, 2018).

Civil engineers coordinate with contractors, regulatory bodies, and community stakeholders through structured consultation processes. Software engineers participate in sprint reviews and technical discussions where they present design rationale, defend architectural decisions, and negotiate trade-offs (Galster et al., 2024). Mechanical engineers engage in design failure mode and effects analysis (DFMEA) meetings, and manufacturing reviews where precise documentation directly impacts product quality and safety (ASME, 2018). These patterns reflect a broader principle: engineering decisions are often made in meetings and thus engineers must structure discussions, manage time, elicit diverse input, and document outcomes clearly.

Communication breakdowns in meetings have measurable consequences. Specific failure modes include design reviews where critical assumptions go unchallenged, risk assessments where dominant voices suppress dissenting views, and client consultations where engineers fail to actively listen. One example of this is the 1999 Mars Climate Orbiter failure, where the spacecraft was lost because one engineering team used imperial units while another used metric units (Stephenson et al., 1999). This preventable communication breakdown illustrates how insufficient verification in coordination meetings can lead to catastrophic outcomes.

Accessibility challenges present additional risks. Cha et al. (2024) showed that blind and partially sighted engineers often face inaccessible meeting tools, leading to additional labour and reduced participation. Ensuring inclusive meeting practices, such as accessible documentation, structured turn taking, and support for varied contribution modes, helps prevent the exclusion of valuable expertise.

By contrast, systematic meeting practices (clear agendas, defined roles, and rigorous documentation), reduce ambiguity, support (technical) decision making and ensure

traceability. These behaviours align with the expectations of professional engineering frameworks UK-SPEC, ABET, ENAEE, and CDIO.

2.3 Importance for engineering education

Given the centrality of meeting skills to engineering practice, their development demands explicit curricular response rather than incidental exposure. Industry representatives have called on universities to broaden curriculum provision to include explicit professional skills instruction (Craps et al., 2017; Farr & Brazil, 2009). Professional accreditation frameworks reinforce these expectations.

Evidence from engineering education research demonstrates that explicit teaching of meeting skills yields measurable benefits. Structured instruction improves communication clarity: activities such as 'Chinese whispers with a twist' (a variation of the well-known communication game that demonstrates how messages change as they are passed from person to person), incorporating rules and feedback sessions, led students to actively reflect on effective communication and gain awareness of the variation in communication styles and possible barriers (Leandro Cruz et al., 2022). Video-based training, focused on face-to-face meeting communication skills, demonstrated significant improvements in both conceptual knowledge and practical skill application, with measurable gains in empathetic engagement, expression of feelings, and contribution of ideas (Galster et al., 2024).

Structured modules like CyberAmbassadors' 'Teaming Up' project showed significant cultural shifts, including widespread adoption of meeting agendas and standardised roles within participating companies (Luchini et al., 2021), leading to more reliable coordination. These results reinforce that meeting skills improve through systematic instruction, practice, and feedback.

Current educational approaches fail to address these documented needs adequately. Despite widespread use of project-based learning, structured instruction in meeting skills remains rare, with students typically receiving exposure without systematic feedback (Craps et al., 2017). Without explicit instruction, students frequently develop 'skilled incompetence', prioritising team harmony and grades over critical assessment of contributions and outcomes (Malzahn et al., 2011). While team projects are common in engineering curricula, they prove insufficient for fostering effective meeting behaviours without structured guidance in agenda creation, role assignment, active facilitation, and inclusive participation management (Selinger, 2010).

The importance of meeting skills extends to broader goals of inclusion and accessibility. Inclusive meeting practices benefit all participants, not just those with specific needs. Explicit training, which clarifies roles and standardises practices, harmonises approaches between teams and encourages orderly meeting culture (Luchini et al., 2021). Understanding diverse communication styles, through frameworks like the Myers-Briggs Type Indicator, helps students recognise that *"people are inherently different and that all personality types are needed for a team to function effectively"*, encouraging equitable participation (Honour Werth, 1996, p. 262).

Taking all of this together, here is what we recommend for engineering curricula:

- Provide explicit instruction and structured feedback on meeting facilitation, participation, and documentation;
- Provide structured meeting practice opportunities with targeted feedback;
- Embed meeting skills into assessment criteria;
- Sustain these practices across progressive levels of study.

3 Forms of implementation

In this section, we share practical methods for teaching meeting skills. Building on the frameworks and evidence from Sections 1 and 2, we have designed these approaches to be scalable, inclusive, and adaptable across diverse institutional contexts. The emphasis is on actionable recipes rather than theoretical discussion, enabling you to implement effective meeting skills development within existing programme structures without adding substantial contact hours.

3.1 Level of study and progression

Teaching of meeting skills requires scaffolded progression from structured, low-stakes environments to more complex and autonomous situations, integrating interpersonal (reading body language, managing personalities, building rapport), technical (using meeting software, creating agendas, taking minutes), and strategic (making decisions, managing time and resources) skills. These cannot be learned in isolation because they can only be effectively developed when combined in real social situations.

Research consistently demonstrates that authentic professional contexts yield stronger skills development compared to artificial academic exercises, with students valuing meeting practice in realistic engineering situations for their future careers, as shown by Changpueng and Pattanapichet (2024). They demonstrated a three-stage flipped classroom model, from asynchronous pre-class preparation (watching videos, listening to journals, writing minutes), to synchronous in-class practice, and finally through group work with teacher feedback and post-class autonomous application (group meeting for video creation), which proved effective for third-year engineering students.

Farr and Brazil (2009) propose that leadership skills develop throughout an engineer's career, beginning with formal education, followed by on-the-job training and mentorship, culminating in self-actualisation as engineers mature into positions of increasing responsibility. They advocate for integrating leadership attributes into engineering curricula, suggesting practices such as rotating students as group leaders in design projects, making leadership performance a significant part of their grade, and emphasising strong communication, as these attributes are central to effective meeting practices.

Effective meeting habits emerge from regular practice across increasingly complex scenarios. This progression typically follows three stages:

- Stage 1 (Fundamentals) provides highly structured and supported experiences with built-in meeting time during workshops to create a safe environment for

initial practice, including staff presence during meetings, template-driven agendas and minutes, and assigned or rotating roles (chair, note-taker, timekeeper). Basic inclusive behaviours can also be practiced here, such as the A-E prompts used at Sheffield University, UK (see Example 1);

- Stage 2 (Coached Autonomy) transitions to self-scheduled meetings where students manage timing independently and take more ownership with less prescription and lighter scaffolding but support remaining available from staff on request;
- Stage 3 (Professional Practice) expects student-led, fully autonomous meetings applied in authentic engineering contexts, involving professional-style interactions with industry partners or mentors, with minimal intervention from staff but optional support if challenges arise.

In more advanced sessions, you can introduce practice-based facilitation tools that align implicitly with literature, such as:

- *Concerns register*. A running list where participants log objections during technical discussions, supporting active listening and rigorous decision making, which links to teamwork and communication competencies emphasised in ENAEE and ABET;
- *Devil's advocate*. One participant is designated to challenge assumptions before decisions are finalised, reflecting the structured criticality required in professional engineering reviews and the risk themes emphasised in Section 2;
- *Translation checkpoints*. After each agenda item, a participant from a different discipline restates the decision to check shared understanding, which aligns with cross-disciplinary coordination in engineering practice.

Accessibility and inclusive practices should be embedded from the outset, not treated as advanced skills. Structured formats such as templates, agendas, and minutes accommodate diverse processing styles and enable asynchronous participation. Multiple contribution modes accept verbal, chat, typed, and asynchronous inputs, with captions enabled where video is used. Scheduling through built-in workshop meeting time avoids external scheduling barriers, while explicit team agreements address diverse communication preferences and needs. Distributed leadership through role rotation ensures all students experience facilitation responsibilities, not just dominant voices. Direct support includes proactive outreach to students with learning support needs and flexible use of assistive technologies.

Example 1. Teaching meeting skills in a Mechanical Engineering Programme at the University of Sheffield, UK

The Mechanical Engineering programme at the University of Sheffield illustrates how meeting skills can be scaffolded across all undergraduate levels.

Year 1 — structured foundation. Meeting skills are introduced in team-based project modules based on real-life engineering scenarios. Teams create Team Operating Agreements defining communication methods, decision making processes, meeting frequency, and roles. Weekly meeting minutes are required using a provided

template. Meetings are held during structured workshops with staff present. Supporting activities include Diversity Confidence in Engineering tutorials, introducing A-E prompts (Actively listen, Build on ideas, Consider others, Define how to work, Evaluate inclusive skills) and a Communicating with Engineers workshop covering workplace communication. Structured roles are introduced: Team Leader, Secretary, and Project Manager.

Year 2 — coached autonomy. Students participate in a teamwork refresher workshop and create a new Team Operating Agreement from a blank template, fostering ownership. Meetings become self-scheduled, requiring more autonomy, but module leader support remains available on request.

Year 3 — professional context. The Group Design Project involves industrial partners, with students supported by academic and industrial mentors via regular meetings. A Mentor Meeting Checklist guides preparation, in-meeting actions, and post-meeting follow-up including creating agendas, assigning chairs and note-takers, and providing peer feedback. No new formal training takes place at this stage; students apply habits established in Years 1-2, with mentor support available if needed.

Year 4 — full autonomy. Students take full ownership of their meetings while retaining the option to seek module leader support when necessary. Built-in peer feedback time is included in meetings, although it is not graded. The emphasis is on consolidating autonomy and professionalism in meeting conduct.

Reflection integration. In Years 1-2, students provide peer feedback using the Buddycheck tool and complete assessed reflections on teamwork. In Years 3-4, reflection shifts to in-meeting peer feedback.

Inclusive practices. Role rotation, explicit communication agreements, accessible documentation formats, built-in meeting time during workshops, and direct outreach to students with learning support needs are embedded from the start and sustained throughout the programme.

3.2 Evidence-based teaching methods

Several pedagogical approaches have demonstrated effectiveness in developing meeting skills through authentic practice within engineering contexts, supported by research in engineering education.

Video-based active learning approaches

Digital platforms offer scalable methods for developing meeting facilitation competencies. Galster et al. (2024) demonstrated significant improvements in both conceptual knowledge and meeting behaviours through 'active video-watching' exercises integrated into software engineering project modules. Students completed weekly online activities critiquing meeting scenarios with minimum intervention from the instructors. This approach also facilitated resource efficiency for large-scale implementation. Similarly, Changpueng and Pattanapichet (2024) developed a fully

online flipped-classroom model focusing on “*conducting group meetings and writing meeting minutes*” for engineering students, described in the previous section.

Problem-based collaborative learning

Simulating workplace scenarios streamlines the transfer of meeting skills to professional practice. Rahimi and Blackstone (2025) implemented a workplace communication workshop for engineering interns using a so-called ‘Activity Theory’ framework. Students engaged with fictional (yet realistic) on-the-job scenarios requiring them to “*write effective meeting agendas, take meeting notes, and prepare concise meeting minutes*”. This problem-based approach connected theory to practice, with faculty and employers identifying meeting skills as critical gaps requiring structured attention.

More broadly speaking, the integration of realistic meeting exercises within project-based learning proves to be particularly effective. Strategies for recording entries in engineering logbooks should encourage teams to document group meetings using guided reflection prompts, such as ‘*What were the main outcomes?*’ and ‘*Was the meeting productive, and why?*’ This on-the-job style approach highlights practical behaviours in terms of timekeeping, role allocation, and reflective follow-up, without requiring additional contact hours.

Curriculum integration strategies

Systematic integration of transferable skills across engineering programmes demonstrates greater effectiveness compared to integrating such skills in standalone modules. Eichhorn et al. (2010) developed a comprehensive framework embedding communication skills throughout four-year programmes without adding separate modules. Their progressive approach moves from foundation modules addressing interpersonal communication to advanced applications in senior design projects, ensuring meeting and communication competencies develop alongside technical expertise.

Carlsson et al. (2010) propose ‘communicating-to-engineer’ frameworks that integrate learning-to-communicate with communicating-to-learn approaches. This approach positions communication tasks, including meeting facilitation, as serving actual engineering functions rather than abstract skills development. Students engage in design communication activities where they use meetings to negotiate, perform, and present engineering projects akin to real-world scenarios.

Assessment-integrated methods

Peer assessment frameworks provide evaluation opportunities whilst developing meeting competencies. The use of the Individual Peer Assessed Contribution (IPAC) method and tool (Garcia-Souto et al., 2020), developed at University College London, UK, and embedded within project evaluations, encourage reflection on communication effectiveness. Students rate peers on attendance, effort, communication, contribution, respect, collaboration, and work standards; these being criteria directly relevant to meeting participation quality.

3.3 Resource requirements and adaptability

Teaching meeting skills or embedding them into engineering programmes and/or curricula calls for flexible resource frameworks that accommodate diverse institutional contexts, a wide range of cohort sizes, and technological capabilities, all whilst maintaining pedagogical effectiveness. Successful initiatives prioritise adaptability over standardisation, enabling you to embed meeting competencies within existing limitations.

Scalable technology integration

Using digital platforms, including learning management systems (LMSs), shared repositories, and streaming technology, provides cost-effective solutions for large-scale implementation. Galster et al. (2024) established that active video-watching platforms require minimal ongoing instructor intervention once configured, making the approach scalable for large-size cohorts.

Online flipped-classroom models (Changpueng & Pattanapichet, 2024) also demonstrate particular adaptability across delivery modes, accommodating both on-campus and distance-learning contexts whilst maintaining interactive meeting practice opportunities.

Online polling systems, chat prompts, and collaborative document platforms enable inclusive participation without imposing additional workload. These technologies prove particularly valuable for international students or those with communication difficulties or disabilities, providing alternative contribution methods whilst maintaining realistic meeting dynamics.

Flexible implementation frameworks

Resource-conscious approaches embed meeting skills within existing programmes to avoid the need for additional contact hours if they would be run as separate modules. Integration within project-based learning, laboratory sessions, and design workshops maximises impact whilst respecting timetable constraints. Engineering logbooks require only standard documentation tools, transforming routine project meetings into structured learning opportunities.

Furthermore, multidisciplinary collaboration enhances resource efficiency whilst improving pedagogical outcomes. Eichhorn et al. (2010) established that partnerships between engineering science faculties and social/communication science faculties enable comprehensive skills development without duplicating expertise. Match-making communication specialists with engineering faculty thus leads to optimisation of resources across disciplines.

Institutional adaptability considerations

Managing large cohorts requires systematic approaches that maintain individual attention whilst accommodating scale. Managing programmes with 400+ students, such as the Integrated Engineering Programme (IEP) programme at University College London (UCL), UK, necessitates integration or embedding of transferable skills, such

as meeting facilitation, within existing workshop sessions, supported by postgraduate teaching assistants (PGTAs) who circulate among teams to provide targeted guidance (see Example 2). This model distributes facilitation load whilst providing personalised feedback on meeting dynamics.

Example 2. Use of automated assessment

Automating assessment reduces marking workload whilst maintaining evaluation quality. Use of tools like IPAC and digital peer evaluation systems enable data collection and analysis without proportional increases in faculty workload. Reviewing aggregated feedback for 50-60 students typically requires 1-2 hours, representing manageable investment in time and effort, given the transparency and fairness benefits that are offered in return.

International and multicultural contexts require additional consideration for inclusive participation. Diverse communication styles, language proficiencies, and cultural meeting norms necessitate flexible facilitation approaches. Structured roles, clear participation guidelines, and alternative contribution methods help ensure equitable engagement across culturally diverse engineering cohorts.

Sustainable implementation strategies

Long-term sustainability requires integration with institutional quality assurance panels and professional accreditation frameworks. Aligning meeting skills development with ABET, EUR-ACE, or UK-SPEC requirements ensures continued institutional support whilst addressing employer expectations for graduate communication competencies, which includes effective participation in and facilitation of (professional) meetings.

Partnerships with industry placement programmes or internships provide authentic contexts whilst reducing resource demands on academic departments. Workplace communication workshops for returning interns (Rahimi & Blackstone, 2025) leverage industry experience whilst providing structured reflection opportunities that benefit both students and employers.

Looking forward to the future, the use of artificial intelligence (AI) tools for moderating peer feedback, identifying communication patterns, and providing personalised development recommendations could improve educational outcomes across diverse institutional contexts, while reducing the load on academics, provided such tools are used properly and ethically.

4 Recommendations for implementation and learning

In this section, we share practical recommendations for the teaching and practice of meeting skills. Building on the implementation strategies outlined in Section 3, the recommendations below help you embed meeting skills effectively, including in more complex engineering meeting scenarios. These recommendations apply across different delivery modes, levels of study, and team structures.

4.1 Key recommendations: putting the foundations into place

In this subsection, we present key recommendations grounded in educational research and practical experience.

Embed low-stakes practice opportunities early in curricula

Felder et al. (2011) demonstrate that inductive presentation — beginning with specific challenges, guiding to strategies, then generalising with theoretical backing provides optimal learning outcomes. In the context of engineering education, this translates into starting with brief formative exercises that introduce fundamental meeting structures during regular tutorial slots.

Use simple, reusable templates: a one-page agenda covering title, objectives, attendees and roles, timed agenda items, expected outcomes, and action tracking, plus an observer checklist. For accessibility purposes, provide materials in advance in screen-reader-friendly formats with high contrast, and offer alternative contribution routes such as typed chat, shared document comments, pre-recorded audio, or speaking. Example 3 presents a simple yet effective practical example.

Example 3. Formative meeting skills exercise

A typical 35-minute tutorial exercise could include: briefing (5 minutes), role-play meeting (10 minutes), observer feedback using structured checklists (10 minutes), tutor summary (5 minutes), and individual reflection (5 minutes). Role allocation involves one chair, one note-taker, two role-players presenting core issues, two to four observers completing structured checklists, and the tutor providing targeted feedback.

Implement continuous student feedback mechanisms

The IET (2015) recommends regular review cycles, progress monitoring systems, continuous improvement mechanisms for maintaining meeting effectiveness. Use brief end-of-meeting feedback (verbal or via short polls) asking what went well and what could be improved. Review engineering logbooks over time to identify recurring issues such as poor timekeeping, dominance behaviours, lack of clear action ownership, or communication difficulties.

Establish regular role rotation

Professional Engineers Ontario (2023) discuss cross-cultural awareness strategies and accessibility accommodation procedures that support effective role rotation. Rotating chair, note-taker, timekeeper, and presenter ensures all students develop comprehensive meeting skills. However, accessibility needs should be accommodated by asking about them in advance and adjusting roles accordingly; some students may require consistent roles, while others benefit from variety.

Engage real stakeholders in simulation scenarios

NASA project management protocols emphasise stakeholder engagement rules and clear reporting structures. Drawing on these, you can use design reviews with client

representatives, planning sessions with multiple stakeholder perspectives, or technical problem-solving meetings involving resource constraints to create authentic meeting experiences.

In addition to stakeholder involvement, scenarios can also incorporate engineering-specific complexities such as cross-disciplinary misunderstandings or disagreements on technical direction. Brief simulation prompts can require students to justify design decisions, articulate risks, or request clarification across disciplines, mirroring real engineering review environments as described in Section 2.

4.2 Do's and don'ts

The following dos and don'ts can be used as a practical checklist to reinforce effective meeting behaviours.

Table 2.3.1: Facilitating inclusive practices

<i>Do's</i>	<i>Don'ts</i>
Circulate concise agendas and expected outcomes at least one week in advance.	Assume everyone knows how to chair or document meetings; teach and practise these skills explicitly.
Ask for accessibility requirements in advance through meeting invitations.	Hide accessibility choices; make them explicit and normalise alternative participation methods.
Normalise multiple contribution routes (speaking, chat, shared documents, pre-recorded audio).	Rely on single-mode participation that may exclude students with varied communication needs.
Provide materials in accessible formats with accessibility-friendly fonts and high contrast.	Use educational jargon or appear prescriptive without practical application.
Allocate buffer time (approximately 15 minutes per hour) and be explicit about time limits for each agenda item.	
Use structured feedback mechanisms with specific, constructive and actionable guidance.	

Table 2.3.2: Integrating meeting exercises with engineering deliverables

<i>Do's</i>	<i>Don'ts</i>
Embed evaluation of meeting skills within existing (peer) assessment frameworks using criteria such as attendance, effort, communication, contribution, respect, collaboration, and standard of work.	Create separate standalone assessment criteria for meeting skills that increase the rubric setting and marking burden.
Connect meeting skills to project outcomes and professional documentation captured in engineering logbooks.	Treat meeting skills as supplementary activities rather than core professional competencies.
Use automated virtual learning environment (VLE) tools (institutional systems) for collecting and aggregating peer evaluation data.	Let meetings routinely overrun; reschedule instead.
	Make assessment compliance-focused rather than development-focused.

Table 2.3.3: Providing clear role descriptions

<i>Do's</i>	<i>Don'ts</i>
Provide specific and consistent role descriptions. Chair opens meeting, follows agenda, manages time, invites contributions, and closes with decisions. Note-taker records key points, decisions, and actions with deadlines. Observers complete checklists and prepare structured feedback.	Assume role clarity without explicit instruction and practice opportunities.
Use consistent templates so students focus on meeting skills rather than role confusion.	Change role expectations between sessions without clear communication.
Ask for volunteers for additional roles such as the use of AI for technology or chat moderation.	Overload single individuals with multiple responsibilities (especially in hybrid meetings).
Explain housekeeping rules upfront, including contribution methods and camera or microphone expectations.	Use roles punitively or as behaviour management rather than as skill development tools.

Table 2.3.4: Conducting thorough debriefings that address both content and process

<i>Do's</i>	<i>Don'ts</i>
Include structured reflection time (2-3 minutes) for all participants including role-players.	Rush debriefings or treat them as optional add-ons to the main activity.
Use observer feedback protocols with specific evidence-based comments rather than general impressions.	Focus solely on content outcomes while ignoring collaborative process learning.
Address both technical outcomes (decisions made, actions assigned) and process effectiveness (accessibility & inclusion, time management, quality of facilitation).	Provide feedback without specific behavioural evidence or suggestions for improvement.
Link reflections to upcoming assessments and professional development goals.	Make debriefings evaluative rather than developmental.

Table 2.3.5: Advanced engineering contexts

<i>Do's</i>	<i>Don'ts</i>
Encourage structured dissent by inviting participants to raise technical objections before closing an item; this prevents premature consensus.	Close decisions without explicitly inviting objections or concerns, especially during technical discussions.
Use translation checkpoints by asking a participant from a different discipline to restate the decision and its rationale before documenting.	Assume shared understanding across disciplines; what appears clear to one domain may be ambiguous to another.
Require rationale capture (why) alongside decisions (what) and actions (who/when) in minutes, reflecting engineering traceability expectations.	Allow hybrid participants to become passive listeners; ensure they have equal opportunities to influence decisions.
In hybrid meetings, adopt a remote-first contribution sequence and use a designated person to relay chat contributions.	Create informal <i>corridor decisions</i> that contradict or replace meeting outcomes.
When simulating design reviews, assign a review authority role so students learn to respond to escalation or conditional acceptance of work.	

4.3 Lessons learnt

Our recommendations are complemented with strategies for the ongoing development of meeting skills.

Reflective journal and reporting practices. Engineering logbooks serve as vehicles for reflective practice when monitored regularly, often referred to as reflective journals when used as such. Indicators include dated entries, diagrams, reference links, cited extracts, and evidence of regular minute or note recording. Emphasise developmental evidence: how meeting skills evolved, which strategies proved effective, challenges encountered, and links between meeting effectiveness and project outcomes.

Student co-creation of criteria. Felder et al. (2011) recommend participant feedback loops for continuous improvement. Involve students in co-designing participation and assessment criteria to recognise diverse communication styles. This ensures assessment frameworks capture meaningful collaborative behaviours without penalising legitimate differences in communication or accessibility needs.

At programme level, aggregated patterns from peer assessment or observer checklists can indicate whether a cohort requires additional guidance. For example, if action ownership is consistently weak across multiple teams, this may signal the need to introduce decision-closure activities earlier in the curriculum.

4.4 Attention points

In this section, we look at critical implementation factors.

Logistics planning for physical and virtual accessibility. Effective implementation requires systematic planning for diverse participation needs. For hybrid meetings, ensure participants can see one another and the shared materials. Provide backup access routes such as a dial-in option. In minimal-resource contexts, simple arrangements using a laptop, basic microphone, and reliable internet are sufficient.

Assessment fairness considerations for diverse participation styles. Moderate peer assessment carefully to address potential bias. Blind review of written peer feedback helps identify patterns of concern, and follow-up conversations should be developmental, starting with the student's own reflection. Use structured Likert scales with behavioural descriptors to support fair judgement.

Inclusive participation alternatives. Begin with fundamental meeting principles and provide multiple contribution modes. Anonymous peer feedback and structured checklists support those uncomfortable with direct critique. Briefly acknowledge cultural influences on communication preferences but prioritise providing choices while maintaining consistent learning outcomes.

Considerations for diverse meeting settings. In multidisciplinary engineering settings, attention should be paid to ensuring shared understanding. Translation checkpoints, where a participant from a different discipline restates a decision in their own words, help prevent misalignment. Hybrid meeting bias should also be monitored; in-room

participants may inadvertently dominate unless roles and facilitation protocols ensure equitable input.

4.5 Adaptability considerations

This subsection addresses adaptation for large cohorts, low-resource environments, online delivery contexts, culturally diverse settings, and interdisciplinary project environments.

Large cohorts. Use postgraduate teaching assistants (PGTAs) to provide scalable coaching across teams. Onboarding should cover responsibilities and use role-play to prepare PGTAs for supporting facilitation. Embed meeting skills within existing tutorial slots; use micro-tasks when full role-plays are impractical. Focus PGTA coaching on observation and formative feedback.

Low-resource environments. Embed meeting skills into existing contact hours. Use institution-supported tools and simple templates. Automate peer assessment collection where possible and prioritise reusable checklists requiring minimal preparation.

Online delivery. Keep meetings to manageable lengths with breaks; use breakout rooms for small-group practice. Provide multiple access options and allow asynchronous contributions such as pre-recorded presentations or shared document collaboration.

Culturally diverse settings. Begin with fundamental principles and provide varied contribution modes to accommodate communication comfort levels. Use structured observation rather than open-ended cultural comparison. Accommodate time zones through recorded sessions or session repeats where needed.

Interdisciplinary project environments. Interdisciplinary project environments may require additional facilitation guidance. Pairing cross-discipline observers, using translation checkpoints, or ensuring interdisciplinary action reviews helps students practise navigating technical vocabulary differences and integration challenges.

4.6 Student perspective

Students often report that clear structure, role descriptions, regular debriefs, and multiple contribution modes allow them to engage more confidently. These practices support participation for students working in a second language, students with accessibility needs, and those new to professional meeting expectations.

4.7 Continuous improvement

Use reflective logbooks to monitor progress and support student development. Refine peer assessment criteria with student input to ensure they recognise diverse forms of effective participation. Review aggregated behavioural patterns periodically to identify curriculum-level needs and introduce interventions earlier where required.

Together, the previous recommendations facilitate the development of transferable meeting competencies while respecting diverse cultural approaches to collaborative work and communication styles.

4.8 Resources and Further reading

In addition to the literature referenced in this chapter, we also suggest *Designing and Facilitating Meetings* by MIT Human Resources (n.d.) and *Effective Meetings Skills* by Haynes (1998).

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AI statement

During the preparation of this work, the authors used ChatGPT (OpenAI) to facilitate a structured dialogue to elicit and consolidate the authors' personal experiences and to help identify suitable literature via its Deep Research function; and NotebookLM (Google) to collect relevant articles and extract core points from each reviewed source. They used Microsoft Copilot (enterprise edition) to provide targeted guidance for revising the chapter in response to peer review feedback. No tool or service was used for the actual writing or authoring of the chapter text. After using these tools, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

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2.4

Risk Analysis and Risk Management Skills

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Risk analysis and risk management are foundational skills for engineers, traditionally taught using structured industrial methodologies such as Failure Modes and Effects Analysis (FMEA) and risk registers. However, the integration of software systems, global supply chains, and artificial intelligence has introduced new categories of risk — technical, ethical, environmental, systemic, and security related, that existing tools only partially address. In this chapter, you will be introduced to a framework that integrates established risk approaches with systems thinking, ethical reasoning, and professional judgement. The chapter moves beyond failure-focused models to explore questions of who benefits, who bears risk, and who holds decision-making power. It provides guidance on curriculum design, learning activities and assessment approaches, including scenario-based learning, project-based learning, ethical risk analysis, and behavioural marker systems for observing skills such as judgement, communication, and responsibility. Strategies are suggested for embedding risk education across programmes. Overall, the chapter supports you in preparing students for a complex and evolving risk landscape where uncertainty and moral considerations are as central as technical assessment

1 Definition

At its simplest, *risk* is the possibility of an adverse outcome. It is typically expressed as a combination of the consequences of an event, and the associated likelihood and severity of occurrence. The term itself derives from the Italian *risco*, meaning danger. In engineering, risk analysis refers to the systematic identification, evaluation, and mitigation of factors that could negatively impact outcomes.

In engineering education, it is important to distinguish between the processes of risk analysis and risk management, and the skills which articulate the ability to carry out these processes. In this context, risk should be understood more widely as '*anticipation of adverse outcomes before failure occurs*'. These outcomes are not constrained to technical domains or immediate users or operators; rather they extend across social, environmental and ethical domains. In education, the priority must therefore be cultivating a mindset that equips students to recognise, question, and evaluate uncertainty systemically.

Risk analysis refers to this systematic process of identifying potential adverse events, evaluating their causes, estimating likelihood and severity, and analysing possible consequences. Risk management refers to the broader decision-making process through which risks are prioritised and addressed, encompassing actions such as mitigation, monitoring, and acceptance of residual risk.

Risk analysis and risk management skills describe the *capability of the engineer* to enact these processes effectively in practice. These skills extend beyond the application of tools and methods to include judgement under uncertainty, the ability to balance competing values, and responsibility for decisions that affect different stakeholders. In contrast to domain-specific processes such as project management, which focus on planning and delivery, risk-related skills are primarily concerned with navigating uncertainty, anticipating unintended consequences, and making defensible decisions in situations where outcomes are incomplete, contested, or unknown.

Graduates who can anticipate risk, communicate uncertainty, and balance competing values are therefore better prepared for roles that demand professional judgement rather than routine technical execution.

1.1 ISO 3100: key concepts and steps

The International Organization for Standardization (ISO) 31000 standard (ISO, 2018) defines risk as the "*effect of uncertainty on objectives*" and sets out principles of integration, structure, and continual improvement. The standard defines eight key terms, as shown in Fig. 2.4.1:

- *Risk*: the effect of uncertainty on objectives;
- *Risk source*: the element which alone or in combination has the potential to give rise to risk;
- *Event*: an occurrence or change of circumstance;
- *Consequence*: of an outcome or event;
- *Likelihood*: the chance of something happening;

- *Risk identification*: the process of finding and recognising risks;
- *Risk analysis*: the process of understanding the nature of risks and its characteristics;
- *Risk evaluation*: the process of comparing results of analysis with criteria to determine significance.

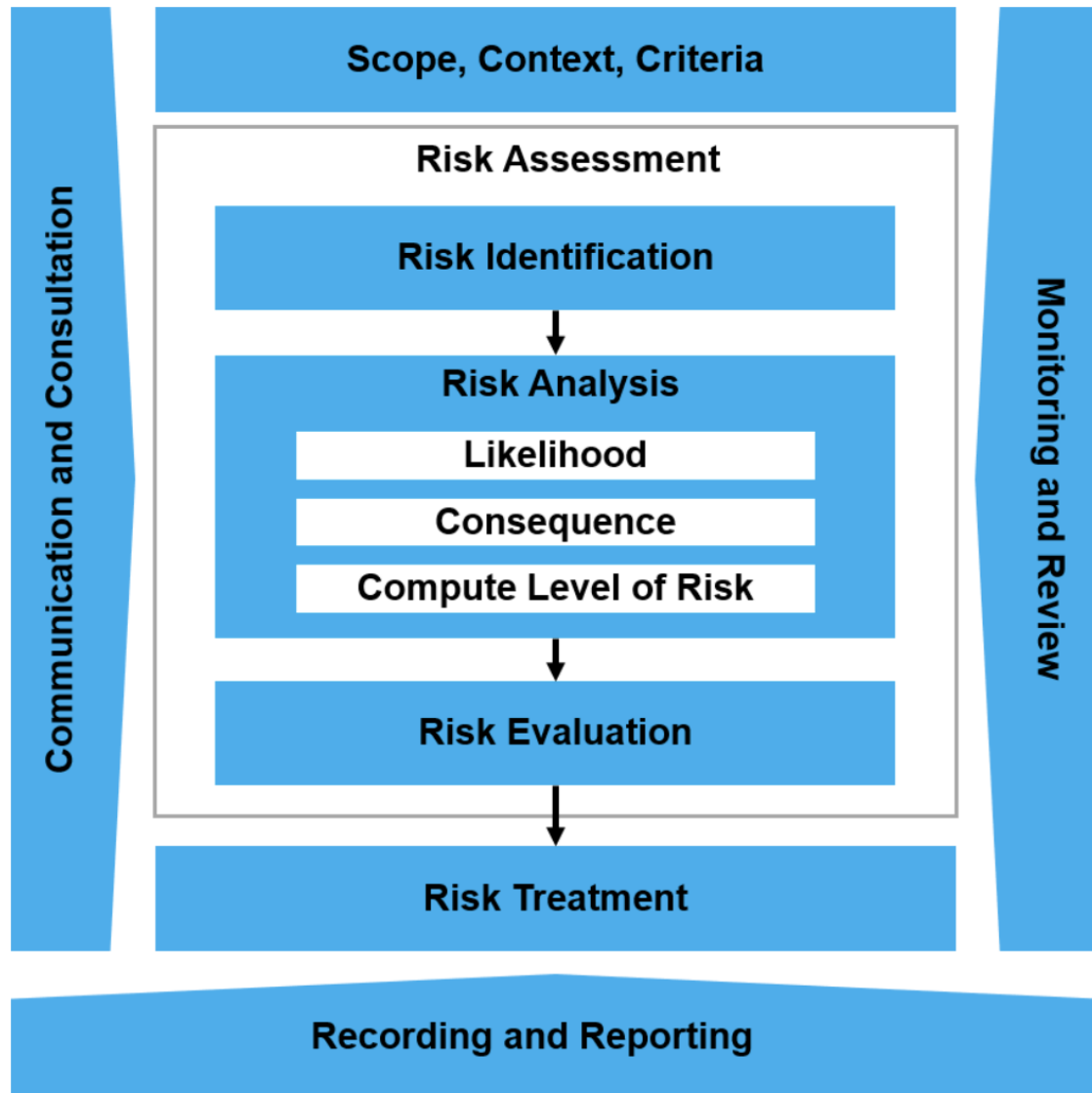


*Figure 2.4.1: ISO 3100:2018 Risk management process, by ISO, 2018.
Copyright 2018 by International Organization for Standardization.*

The framework is operationalised through seven iterative steps (summarised by Marlin et al., 2019) including context establishment, identification, analysis, evaluation, treatment, communication, and monitoring.

ISO 31000 emphasises embedding risk management into organisational culture, focussing less on prescribing processes and more on integrating risk thinking into decision making.

1.2 Related frameworks

The NASA Systems Engineering Handbook reinforces similar principles: identifying technical risks, analysing likelihood and consequences, developing handling strategies (avoid, accept, monitor, mitigate), documenting and communicating, and integrating into engineering decisions.

- *Avoid* means redesigning systems or decisions to remove the risk entirely (e.g., eliminating hazardous materials, removing unsafe processes, or preventing exposure).
- *Accept* means recognising that some risks cannot be eliminated (at least cost-effectively) and therefore making an explicitly decision to tolerate them. This may be based on proportionality, benefit, and ethical defensibility.
- *Monitor* means monitoring risk indicators over time, using early-warning signals, inspections, and other control loops to detect emerging problems before harm occurs.
- *Mitigate* means reducing the severity of the outcome through safeguards, design, or protective measures.

Risk analysis relates closely to systems thinking, decision making and professional ethics, and includes safety, health, environmental, security, and (as we urge you to incorporate) ethical dimensions.

1.3 Safety, health, and environmental (SHE) risks

Many engineering risks are systemic, arising not from a single technical failure but from interactions between technical design, regulation, organisational practice and societal values. The Institution of Engineering and Technology (IET)'s (2012) framework for incorporating safety, health, and environmental (SHE) risk into curricula stresses that graduates must engage with SHE risks within their regulatory, ethical, and governance contexts. Embedding SHE across the curriculum rather than within specialist safety modules ensures all engineers engage with long-term environmental and health consequences of their work. Case examples which illustrate such systemic risks include Grenfell Tower (London, United Kingdom), which combined safety and environmental risks with governance breakdown, and the VW Diesel emissions scandal, which highlights the risks of regulatory evasion in engineering practice.

Security risks introduce qualitatively different challenges. Unlike safety risks, security threats arise from deliberate intent: the attacks on the Ukrainian power grid illustrate the weaponisation of risk. Cyberattacks, sabotage, insider threats, social engineering, and terrorism all expose vulnerabilities. Students must understand not only failure probabilities but also adversarial behaviours. Defences must be layered and adaptive. Exercises such as red team-blue team simulations illustrate how attackers might probe weakness across multiple layers of defence by assigning students to either attacker or defender roles.

1.4 Balancing prudence and innovation

Excessive risk avoidance can stifle innovation, while reckless risk-taking can undermine safety and public trust. Engineers must learn to balance prudence with creativity, resilience with responsibility. The challenge might be summarised as: *what do we do when we don't know what to do?* Students must be taught to become habitual in their responses to such dilemmas.

2 Conceptual foundations of risk

2.1 Traditional framing

Risk is inherent in all engineering activities. Traditionally, engineers treat risk as a subset of failure analysis, focussing on how things might break, and the consequences of these failures. Students should therefore be introduced to fault-based approaches such as fault tree analysis or Failure Mode and Effects Analysis), which are widely used in industrial contexts to identify, analyse and mitigate failure.

2.2 Where to look for risks

While traditional approaches provide structured process for analysing failure, a key limitation is that they do not explicitly guide students on where to look for risk or how to identify it in complex systems. What students identify as risk will depend on the context, their experience, and what you encourage them to notice. For this reason, students benefit from heuristic tools that help them to actively scan for potential problems and vulnerabilities with a systematic and categorised approach. Several established tools can support this type of structured analysis:

The 5M model (Ishikawa, 1968) directs attention systematically towards specific aspects of the system — man, machine, material, method, measurement, and environment — as potential risk domains. You can utilise this model to help students to examine each potential category of risk across the whole system. For example, students could consider how measurement errors in design, manufacturing, and any embedded control systems might lead to failure of the system.

Fault tree analysis means systematic mapping of causal chains from root causes to outcomes. Teaching students to construct these chains helps them to understand how risk propagates across technical and organisational systems. This approach can be combined with statistical failure analysis to estimate probability of failure through 'chain reaction' as well as identifying the minimum cut set — the smallest combination or sequence of events which will cause failure. Students may find this approach satisfying since it incorporates probability analysis giving numerical outputs. You might utilise this method to analyse a case study which sets out a particularly unfortunate series of events.

Noise analysis, as part of parameter diagrams originating from Taguchi's robust design methodology (Taguchi, 1986), helps students to develop an understanding of noise factors — the uncontrollable external influences on system performance. Students may not naturally consider noise because it is outside of the design space, but resilient and robust systems must be able to maintain performance within a noisy operating

environment. By understanding how noise influences the performance of a system, students can design robust and resilient systems which continue to work regardless of environmental effects such as temperature or moisture, degradation effects over time and misuse by operators.

The *Swiss Cheese Model* (Reason, 1990) frames complex systems as multiple layers of organisational, technical, and human defences with weaknesses in each that arise from design and human errors. Reason visualises each of these weaknesses as a hole in a specific layer; when weaknesses (holes) in multiple layers align, hazards and attacks are able to propagate through the layers of defence. This model is often taught in introductory security modules and can help students to develop holistic awareness of security risks.

When you teach risk, the tools mentioned will help students to go beyond failure analysis. They can be incorporated into exercises and workshops. Your students will learn to anticipate and prevent problems by systematically examining potential vulnerabilities and weak points as part of design and considering the likely effect and outcome. However, we must also teach students what to do in response to this risk.

While these tools support structured analysis and broaden students' ability to scan for risk across systems, they also have limitations. Many remain rooted in failure-based reasoning focussing on known pathways and defined boundaries. As a result, they may not support the identification of emergent or systemic risks. This is particularly significant where students lack the experiential knowledge of prior failures that often underpins their effective use in industry. Developing risk competence therefore requires you to cultivate the ability to anticipate uncertainty and engage with risk across technical, organisational and societal domains.

2.3 Risk, uncertainty, and deep uncertainty

A common metaphor for grappling with complexity in engineering education comes from distinctions in decision theory between perfect knowledge, risk, and uncertainty (Knight, 1921). Under conditions of *perfect knowledge* all possible outcomes and their probabilities are fully specified. Under *risk*, outcomes and probabilities are in principle knowable, even if not yet determined. Under *uncertainty*, however, some outcomes or their probabilities remain fundamentally indeterminate. Finally, *deep uncertainty* describes situations where there is no agreement on, or clear knowledge of possible outcomes themselves, the models that link them, or the probabilities that may be assigned. These epistemic decision-making contexts are summarized in Table 2.4.1.

Table 2.4.1: Epistemic decision-making contexts

Decision context	Definition
<i>Perfect Knowledge</i>	All outcomes and probabilities are fully understood and known
<i>Risk</i>	Recognised gaps where outcomes are known and probabilities can be estimated
<i>Uncertainty</i>	Emerging or unconsidered issues; outcomes known but probabilities unknown
<i>Deep uncertainty</i>	No agreement on possible outcomes, models or probabilities

This tripartite framing has been popularised as known knowns (established), known unknowns (not yet considered), known unknowns, and unknown unknowns, as shown in Table 2.4.2. As a heuristic, it underscores the epistemic boundaries of engineering knowledge.

Table 2.4.2: Risk, uncertainty, and unknowns

Knowledge of outcome	Knowledge of probability	Category	Example
<i>Known</i>	Can be estimated	Risk	Steel bridge design, with well-established material data
<i>Known</i>	Unknown	Uncertainty	New material with untested fatigue properties
<i>Unknown</i>	Unknown	Deep uncertainty	Long-term mobility options, changes to vehicle weights or modalities of transport

Engineering education has historically focussed on *perfect knowledge*: risks with calculable probabilities and clear solutions (Martin et al, 2023). Yet practicing engineers increasingly face *unknown unknowns* (Dalal et al., 2021). This highlights the importance of preparing students not only to solve well-defined problems, but also to navigate ambiguity and unexpected situations. Therefore, you need to equip students to work confidently even when analytical methods no longer apply.

2.4 Normative uncertainty and ethical dimensions

Beyond epistemic challenges, engineering decisions are value-laden. *Normative uncertainty* arises when there is no clearly 'right' option. In that case there are multiple defensible but incompatible courses of action, or alternatively no defensible option is available (Nickel, 2020). This often occurs when disruptive innovations undermine

established moral norms without clearly leading to new ones, thus leaving individuals uncertain of their obligations (Hofbauer, 2023; Taebi et al., 2020).

Understanding this landscape requires attention to four interconnected dimensions. First, *evolutionary uncertainty* addresses how societal values, technologies, and environments will change over time. Engineers designing infrastructure intended to last decades must anticipate not only technical requirements but also shifting societal priorities that may alter how their work is evaluated by the public. Second, *theoretical uncertainty* concerns which ethical frameworks should guide decisions when different frameworks point to different actions and desired outcomes; for instance, whether engineers should prioritize utilitarian calculations that maximise overall benefit or deontological principles that focus on the rights and duties of each individual. Third, *conceptual uncertainty* focuses on which values matter in context and how to operationalise them. Even when engineers agree on general principles like safety, sustainability, or equity, translating these concepts into specific design criteria implies navigating competing interpretations and priorities. Finally, *epistemic uncertainty* extends beyond technical performance to include what can be reliably predicted about impacts across sociotechnical and ecological systems whose behaviour cannot be fully anticipated.

Risk in engineering is never value-neutral. Every risk decision involves ethical judgement about whose safety matters, whose interests are prioritised and whose voices are heard. Teaching risk therefore necessarily involves teaching ethics. These four dimensions highlight that engineering decisions involve more than probabilities or likely outcomes. They are, at their core, about values, duties, and the kinds of futures we choose to create through engineering work.

3 Forms of implementation

The following examples illustrate different ways in which these concepts can be translated into teaching practice, each with specific strengths and limitations.

3.1 From technical risk to ethical risk analysis

Traditional risk analysis asks what the probability of harm is and how severe might it be. In the Integrated Engineering Programme at University College London (UCL), UK, we introduce students to ethical risk analysis (Hansson, 2018, 2022). This approach asks different questions: who bears risk, who benefits, and who decides, and are these decisions morally defensible?

The UCL framework identifies three key roles that people occupy in relation to any engineering activity. The risk-exposed are those who may potentially suffer harm, whether workers subjected to occupational hazards, communities living near industrial facilities, or future generations inheriting the environmental consequences of present decisions. Beneficiaries are those who gain from risk-taking, such as consumers enjoying products, investors earning returns, or societies accessing new capabilities. Decision makers are those whose choices determine the exposure to potential harm, including engineers designing systems, managers authorizing operations, regulators

setting acceptable risk thresholds, and stakeholders who are consulted and can veto or approve projects.

Each role raises ethical challenges. If beneficiaries do not share risks, this raises questions of distributive justice. This is the case with shareholders profiting from industrial operations while workers face daily exposure to hazardous conditions. Decision makers who also benefit face conflicts of interest, as their personal or organizational stakes may bias judgement toward risk acceptance, regardless of the impacts on the risk-exposed. The presence of risk-exposed groups with no benefit and no voice illustrate the most ethically problematic scenario (Hansson, 2017; Okereke, 2018). This is a pattern disturbingly common in environmental justice contexts, where low-income communities and communities of colour bear disproportionate pollution burdens from facilities serving more affluent populations. Ethical risk analysis thus prompts one to take a stance on whether benefits to one group ever fully justify imposing risks on another, and if so, under what conditions.

In practice, students engage with this framework through structured case-based activities (for an example set in a challenge-based learning pedagogical context, see Martin et al., 2024). At UCL, they are presented with engineering scenarios and asked to identify risk-exposed groups, beneficiaries and decision makers, before analysing how risks and benefits are distributed. Students then evaluate whether these distributions are ethically justifiable using tools such as stakeholder mapping, distributional analysis and rights-based reasoning. This is typically done through facilitated discussion, group work or written reflection.

Complementary analytical tools extend this analysis beyond stakeholder identification. Stakeholder mapping visualizes relationships among actors positioned differently and power asymmetries that may distort decision making. Distributional analysis examines whether risk-benefit arrangements are fair given pre-existing inequalities, recognizing that formally equal treatment may be substantively unjust when applied to unequally situated groups. Rights analysis asks whether risk impositions violate fundamental entitlements, beginning from the premise that each person possesses a defensible right not to have risks imposed by others. Power analysis investigates whether decision-making structures give meaningful voice to the most affected and vulnerable populations or instead concentrate authority among those insulated from consequences of their choices. Together, these frameworks extend risk analysis from a technical calculation to a moral practice of balancing fairness, responsibility, and precaution (Martin, 2026).

The approach implemented in the Integrated Engineering Programme offered by UCL enables teachers to move beyond technical risk calculations by making the distribution of risks and benefits explicit and open to judgement. It is particularly effective in helping students to recognise the impact of stakeholder conflict and justice, which are not accounted for within the traditional risk process. A potential limitation is that students may initially struggle with the lack of a clear correct answer, which requires careful facilitation and support to ensure discussions are structured and reasoned rather than grounded in opinion. This approach is best suited to learning environments

where ambiguity and competing priorities can be explored under supervision and in depth.

3.2 Curriculum integration

You can embed risk education across your programme using a developmental approach. Technical risk analysis can be introduced into first-year design projects, with complexity, conflicting perspectives, and ethical reflections progressively built in through upper-level modules. SHE and security considerations can be tied into capstone projects linking compliance with broader questions of accountability to the public and professional judgement.

Example 1. King's College London

King's College London scaffolds student development by embedding risk analysis throughout undergraduate study. It utilises a project-based learning framework to introduce, deepen, and synthesise risk competencies year by year. Students encounter evolving tools matched to their stage of development and to the increasing complexity of projects. In parallel, they are introduced to the risks of engineering practice itself, such as health and safety in laboratories, project management, and research ethics, so that students experience both the technical and organisational dimensions of risk.

In the foundational stage, students are introduced to risk through user-centred design focusing on satisfaction risks. They explore how poor alignment with user needs can create dissatisfaction and failure to adopt. Tools such as the Kano model (Kano, 1984) are used to analyse potential causes of user dissatisfaction, allowing students to distinguish between basic expectations which must be met, performance factors where satisfaction is linearly related to success, and excitement features which are worth the risk because of their reward. At this stage, framing risk in human-centred terms helps students to appreciate that engineering risk is not limited to physical hazards but also includes user and stakeholder trust. At the same time, students complete health and safety inductions for laboratories and makerspaces, and complete simple project risk charters to manage work.

Students then progress onto integration risks, particularly the challenge of hardware-software interactions. Here, model-based systems engineering is introduced to provide a structured framework for managing complexity. By modelling subsystems and their interactions, with a deep focus on simulation, students learn to anticipate and test for integration problems early. In parallel, students appreciate the risks posed by team dynamics and decision-making structures in negotiating design decisions without complete data.

In the intermediate stage (Year 2), students apply more formal failure analysis, sustainability, and commercial risk approaches. They employ tools such as finite-element analysis to evaluate designs as well as utilising forward failure mode and effects analysis to anticipate and prioritise technical failures. At the end of Year 2, students utilise lifecycle analysis to consider environmental risks as well as mapping potential positive and negative outcomes against the UN Sustainable Development

Goals (SDGs). Commercial exposure introduces business and financial risks; here, students use business risk frameworks to explore issues such as market volatility, supply chains, and intellectual property.

Throughout the advanced stage (Year 3), students undertake an individual project in which they are assessed on their ability to plan for and mitigate risks, maintaining active risk registers which are updated dynamically. Professional risks — such as ethical decision making, leadership accountability and compliance with standards and regulations — are explicitly assessed through the individual dissertation. Alongside this, they can take optional modules focussing on manufacturing and deployed operational risks, incorporating learning from statistical quality control and design of experiment.

The developmental approach employed by Kings College London enables a coherent progression of risk competence scaffolding learning from creation of awareness to complex, integrated judgement across technical, organisational, and ethical domains. The strength of a continuous approach is that competence becomes a continual development process rather than an isolated topic and is embedded into other technical contexts. However, it requires strong programme-level oversight and alignment, which can be challenging to implement in some organisational structures. The model is therefore most effective when there is already a programme-level approach to curriculum design.

3.3 Scenario- and case-based learning

Case-based learning offers the opportunity for immersive decision making in which learners imagine themselves in specific scenarios and reflect on the strengths and weaknesses of their own practice (Rae, 2016).

Student perspectives on risk education reveal a persistent challenge: risk is often abstract, procedural, or boring. Students identify strongly with dramatic case studies but cannot situate themselves within those scenarios. Examples include designing resilient infrastructure under climate uncertainty, evaluating AI deployment with unknown social consequences, managing cyberattacks on energy systems, and balancing economic and environmental trade-offs in supply chains.

Here, the uncertainty matrix (Kermisch & Depaus, 2024) provides a valuable pedagogic tool. Students can classify case studies into domains of risk, uncertainty, and deep uncertainty, deciding which analytical and ethical approaches are appropriate. This reinforces the insight that not all engineering problems are reducible to probabilistic calculation.

Case-based learning enables you to situate students within realistic, high-stakes scenarios, helping them to connect the concepts to decision-making experiences. It is useful for developing judgement, reflection, and awareness of uncertainty. A limitation is that without structured guidance, students focus on narrative rather than reasoning and so tools that scaffold the process are essential. When supporting this type of

learning, you must facilitate reflection and ensure students explicitly link back to the conceptual frameworks.

3.4 Ethical and security risk mapping tools

Ethical risk mapping encourages students to classify stakeholders as risk bearers, beneficiaries, or decision makers. Security risk exercises can similarly map potential adversaries, assets, and vulnerabilities, highlighting the intentionality that distinguishes security from other risks.

Building on this, students can be introduced to *normative uncertainty* (Taebi et al., 2020). Exercises can ask them to recognise value conflicts (conceptual uncertainty), debate which ethical theory to apply (theoretical uncertainty), anticipate how values may evolve over time (evolutionary uncertainty), and confront the limits of knowledge (epistemic uncertainty). Embedding these categories into mapping activities helps students see that risk is never only technical, but always entangled with values, norms, and contested futures.

These mapping approaches help your students to visualise the relationships between stakeholders, power, values, and threats — extending risk analysis into social or organisational domains. They are especially useful to help students to understand that risks are shaped not only by systems but also by human decisions and interests. However, these can become conceptually complex and overwhelming, so you should carefully consider the appropriate sequencing in teaching and introduce it progressively, perhaps within case-study contexts.

3.5 Agile and adaptive risk management

Teaching agile methods exposes students to iterative, adaptive risk handling. These complement traditional (linear) risk frameworks, preparing students for diverse industrial contexts. Examples include incremental risks associated with each sprint, red team-blue team simulations, and adaptive sustainability assessments.

Adaptive approaches can also be tied to the precautionary principle (Raffensperger & Tickner, 1999), which holds that the absence of certainty is not a justification for inaction when serious harms are plausible. Paired with participatory mapping — where students consult or simulate the perspectives of affected communities — ensures students see adaptive risk management as both technical and social practice.

Agile and adaptive approaches enable you to expose students to dynamic and evolving risk environments which replicate more realistic ways of working (especially in software or other complex systems contexts). This emphasises iteration, feedback, and adaption over static risk analysis. Students may struggle to reconcile these approaches with more traditional, linear, or waterfall (sequential and stage-gated) risk frameworks and so making the difference explicit can be helpful. Students should already be familiar with the foundational concepts, so that they can reflect on the difference between linear and agile approaches.

3.6 Behavioural marker systems (BMS)

Beyond technical definitions and use of tools, risk competence in engineering can be further defined by breaking the concept into cognitive and behavioural sub-elements. These capture not only what an engineer knows about risk, but how they act under conditions of uncertainty. One way to articulate this is through the use of behavioural marker systems (BMS) adapted from aviation and healthcare (for an overview, see Dietz 2014). These describe the observable behaviours that engineers should demonstrate in practice, and which have been linked empirically to underlying competence and skills. Such frameworks provide structured indicators of good and poor performance across domains such as risk identification, scenario building, interdependency awareness, communication, and compliance.

One such system has been developed at King's College London, UK, as part of the General Engineering Non-Technical Skills (GENTS) Project (Jaberi et al., 2023). An extract from this, as relates to risk, is shown in Table 2.4.3. This summary table defines the sub-competencies of risk management in conceptual terms. A more detailed version with performance descriptors, verbal cues and contextual scenarios is provided as part of the full behaviour marker system (see Lucas and Ciriello (2026) for additional materials, including example videos and assessment frameworks).

Example 2. BMS at King's College London

The BMS developed by King's College London involved literature review, expert workshops, interviews with senior engineers, and validation with video-based scenarios. Its design principles emphasise clarity, observability, and direct links to engineering practice. You can utilise Likert scales to assess performance within project-based learning based on the example behaviours given in the BMS. By defining positive and behavioural markers associated with risk, BMS allows educators to provide structured observation and feedback to students and design role-play and simulation exercises.

The General Engineering Non-Technical Skills (GENTS-NTS) taxonomy extends this approach linking risk and security with broader non-technical competencies such as teamwork, resilience, and ethical reasoning. Within the wider category of "ethical and contextual awareness", the following competencies and behaviours are relevant:

Understanding project context assesses students for proactively scanning regulations, technologies, organisational dynamics, and sustainability factors to frame feasible, compliant, and future-aware engineering work. Positive behavioural markers include inquiring about upcoming or potential legislation relevant to engineering work and discussing how future legislation might constrain or influence potential solutions. Negative markers include ignoring or downplaying non-technical constraints like licensing or geopolitical considerations in technical discussions and passively waiting for explicit instructions regarding sustainability.

Assessing wider societal and environmental impact assesses the systematic examination of who benefits or is harmed, dual-use risks, missing voices, and

broader consequences beyond immediate technical results. Positive behavioural markers include investigating the broader consequences of cost-driven decisions, raising questions about potential negative impacts or unintended consequences, inquiring about who benefits and who might be negatively affected by a project's social or environmental aspects, and probing designs persistently by posing challenging or devil's advocate questions to identify hidden risks or weaknesses. Negative markers include overlooking or ignoring the perspectives of certain individuals or groups, not identifying key elements or factors that are absent from a situation or discussion, and focusing only on implementation details.

Acting reliably and responsibly assesses whether students demonstrate integrity under pressure. Positive behavioural markers include identifying short-term pressures that might conflict with long-term compliance and safety requirements, applying and, where appropriate, exceeding codes and standards, identifying potential conflicts between different obligations, reasoning transparently about risks, applying the "Swiss cheese model" to analyse how multiple small vulnerabilities can create significant failures, and speaking up to protect safety, integrity, and the public good. Negative behaviours include framing ethics as an obstacle, operating at the lowest common denominator defined by codified standards, and compromising safety or compliance due to specific pressures.

Table 2.4.3 Extract of behavioural marker system for risk competence.

Element	Good performance (summary)	Poor performance summary)
<i>Understanding and identifying</i>	Uses structured frameworks, remains adaptable, considers wider context, acknowledges uncertainty	Neglects emerging risks, relies on single sources, assumes risks are fixed
<i>Building scenarios</i>	Develops what-if cases, considers multiple approaches, seeks diverse perspectives	Avoids scenario exploration, disregards conflicting evidence
<i>Awareness of interdependencies</i>	Identifies small risks, applies Swiss cheese model, takes proactive action	Treats risks in isolation, overlooks systemic interactions
<i>Evaluating and mitigating</i>	Stays calm, prioritises severity, follows protocols, analyses holistically	Responds reactively, ignores urgency, blames single causes
<i>Communicating</i>	Informs relevant parties, promotes learning culture, supports trust	Withholds information, discourages reporting, undermines trust

<i>Complying with codes</i>	Ensures compliance, demonstrates integrity, supports no-blame culture	Disregards regulations, misrepresents compliance
<i>Acting reliably and responsibly</i>	Applies and exceeds standards, reasons transparently, speaks up to protect safety and public good	Frames ethics and safety as an obstacle, compromises under pressure
<i>Responding to change</i>	Balances stability with adaptability, maintains awareness, adapts to protocols	Resists adaptation, clings to outdated routines

Behavioural marker systems enable you to assess risk competence through observable actions rather than written outputs, making tacit aspects of professional judgement both visible and assessable. They are particularly valuable when providing structured feedback on behaviours. However, there is a need for trained assessors and calibration exercises to prevent subjectivity between markers.

Taken together, these examples demonstrate that there is no single way to teach risk effectively but rather a set of complementary strategies that can be adapted to different educational contexts. The following recommendations synthesise these into practical guidance for curriculum design and teaching delivery.

4 Recommendations for implementation and learning

Drawing on the conceptual foundations and examples of implementation, the following recommendations provide actionable guidance for embedding risk competencies and skills within engineering programmes.

Adopt a developmental approach. Build risk learning across the curriculum, increasing complexity and integration as students progress. Begin with qualitative tools, then move to system-level analysis and integrative capstone projects.

Embed uncertainty as a learning outcome. Go beyond calculable probability — teach resilience in uncertainty and deep uncertainty. Use the uncertainty matrix to distinguish between risk types, and ethical case debates to highlight value conflicts. Encourage students to be comfortable with incomplete knowledge and reflect on their responses to ambiguity.

Integrate ethics and justice into risk analysis. Risk education should include moral responsibility. Use Hansson's ethical risk analysis framework to identify risk-exposed, beneficiaries, and decision makers. Embed justice concerns in case studies and use participatory approaches to ensure those affected have a voice.

Leverage active and scenario-based learning. Use real-world cases, simulations, and role-play to connect risk concepts to practice. Encourage explicit mapping of uncertainty and reflection on decision making under ambiguity. Highlight voices of those most affected.

Use behavioural marker systems to assess non-technical skills. Observational assessment is more effective than written exams for risk judgement and communication. Behavioural marker systems provide structured feedback on observable behaviours. Use Likert scales and peer assessment in project-based learning to support metacognitive awareness and long-term skill development.

Principles for effective teaching of risk skills

When teaching risk, prioritise approaches that foster deep engagement and authentic learning. Use real cases and simulations to encourage reflection and embed risk into professional practice through activities such as lab inductions, project work, and safety walk-arounds. Integrate risk education across the curriculum, ensuring students encounter it in varied contexts and at different stages of their development. Above all, give students a voice — allow them to build and articulate their own stakeholder perspectives.

Avoid treating risk as a mere compliance exercise or relying solely on mathematical tools, as these can obscure the true nature of uncertainty. Do not separate safety from security or ethics, and refrain from assessing risk competence exclusively through written exams. Remember, genuine risk competence is behavioural and situational, best observed in practice rather than on paper.

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AI statement

During the preparation of this work, Claire Lucas used ChatGPT in order to help her work through reviewers' comments and make direct suggestions for improvements such as keywords to highlight, how to emphasise the first person, and where to include additional information. After using this tool, the author reviewed, edited, and made the content their own as needed. The authors take full responsibility for the content of the publication

Contributor statement

Conceptualisation	Claire Lucas, Diana Martin
Writing - original draft	Claire Lucas, Diana Martin
Writing - reviewing and editing	Claire Lucas, Diana Martin

2.5

Engineering Leadership Development: An Integrated Framework for Practice

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Engineering graduates increasingly operate in complex sociotechnical environments that require judgement, collaboration, and contextual awareness alongside technical expertise. Yet these capabilities are often treated as peripheral rather than intentionally embedded within engineering education. This chapter presents a framework that integrates three complementary approaches to engineering leadership operating at different developmental levels. The Leadership Paradox Compass (LPC) helps learners recognise and navigate tensions inherent in engineering practice, supporting reflection on paradox, ambiguity, and decision making in action. The Engineering Leadership Orientations (ELO) model focuses on professional identity, enabling engineers to understand influence as a legitimate and meaningful dimension of engineering work. The Contextual Engineering Leadership Development (CELD) framework addresses curriculum and pedagogical design, showing how teaming, effectual behaviour, and contextual awareness can be embedded within authentic learning environments. Together, these approaches offer educators a coherent architecture spanning action, identity, and system design. Drawing on empirical research and practical implementation across multiple educational settings, the chapter provides conceptual foundations, practical examples, and guidance for integrating leadership capabilities into engineering programmes.

1 Introduction

Engineering challenges are increasingly sociotechnical, complex, and unpredictable, requiring agility, innovation, contextual awareness, and tolerance for ambiguity alongside technical expertise. When leadership is presented as something separate from engineering practice, learners often struggle to see its relevance. In this chapter, we embed leadership development in authentic engineering contexts through three research-informed models developed by the co-authors' research teams in Poland, Canada, and the United States. Together, these models offer a practical framework operating at three interconnected levels: judgement in action, professional identity, and curriculum design, connecting the why of engineering leadership with the how of developing transferable competencies and skills.

1.1 *What do we mean by engineering leadership?*

We frame engineering leadership as a process rather than a position: purposeful and ethical influence enacted through everyday engineering work to advance engineering outcomes with and through others. It is not defined by formal authority, managerial rank, or charismatic personality traits. Consistent with Kendall et al. (2022), this perspective positions engineering leadership as a sociotechnical practice grounded in technical expertise, stakeholder awareness, collaboration, and responsible decision making.

This understanding moves away from heroic or trait-based views of leadership and instead emphasises observable practices, team interactions, and situated judgement in real engineering contexts. It is also consistent with contemporary perspectives in engineering education, where teamwork, contextual awareness, professional judgement, and responsibility are recognised as essential transferable competencies for engineering practice.

From this perspective, engineering leadership is not a separate discipline added to engineering education, but rather a way of practising engineering well. This shared understanding underpins the three developmental levels presented in this chapter: action, identity, and system.

1.2 *Why engineering leadership matters*

Engineering work rarely involves technical problem solving in isolation. Engineers coordinate multidisciplinary teams, negotiate trade-offs, communicate uncertainty and risk, and align technical decisions with stakeholder needs and broader societal expectations. These activities require leadership capabilities alongside technical expertise.

Leadership development also matters because engineers do not always recognise leadership as part of their professional role. When leadership is framed in ways that connect with engineering identity and authentic professional practice, learners are more likely to engage with its development and transfer these competencies across projects, roles, and career stages.

A contextual and professional practice-based approach to leadership development helps emerging engineers navigate competing demands that characterise engineering work, such as balancing quality with speed, autonomy with alignment, or technical standards with care for people and context. In doing so, leadership development strengthens team functioning, decision quality, and reflective professional judgement.

1.3 Three complementary approaches to engineering leadership development

Engineering educators approach leadership development in different ways depending on context, learner needs, and institutional goals. Rather than promoting a single model, this chapter brings together three complementary approaches presented in order of increasing developmental scope: leadership-in-action, professional identity, and curriculum design.

The Leadership Paradox Compass (LPC) focuses on navigating tensions in engineering practice. Engineering Leadership Orientations (ELO) supports leadership identity formation within engineering. The Contextual Engineering Leadership Development (CELD) framework focuses on embedding leadership development within engineering curricula and authentic learning environments.

Together, these models offer practical approaches for supporting engineering leadership development across diverse contexts.

1.4 How do the models work together?

Engineering leadership development is often addressed through individual frameworks that emphasise different aspects of practice. In this chapter, we integrate three complementary models operating at different developmental levels. All three share a common view of engineering leadership as a learnable and transferable dimension of everyday engineering practice but differ in focus. At the action level, the Leadership Paradox Compass (LPC) helps learners navigate tensions in decision making, collaboration, and trade-offs. At the identity level, the Engineering Leadership Orientations (ELO) model helps learners conceptualize leadership as an integral feature of engineers' professional identity. At the pedagogical level, the Contextual Engineering Leadership Development (CELD) framework supports educators in embedding leadership development within authentic engineering curricula. Together, the models provide complementary responses to different educational challenges, as summarised in Table 2.5.1.

Together, the three models offer educators a coherent but flexible approach to engineering leadership development. LPC supports reflection in action, ELO strengthens professional identity, and CELD enables intentional pedagogical design. Used in combination, they help embed leadership development within engineering education not as an additional subject, but as an integral dimension of engineering practice.

Table 2.5.1: Educational challenges and the contribution of the three engineering leadership development models

<i>Educational challenge</i>	<i>Model</i>	<i>Practical contribution</i>
Learners struggle to navigate tensions and competing demands in engineering practice	Leadership Paradox Compass (LPC)	Makes leadership visible through everyday tensions and supports reflection on leadership-in-action
Engineering students and faculty view leadership as peripheral to engineering practice	Engineering Leadership Orientations (ELO)	Frames leadership as an integral aspect of engineers' identity and professional practice
Educators are uncertain how to integrate leadership development into curricula and programmes	Contextual Engineering Leadership Development (CELD)	Provides a pedagogical framework for embedding leadership development in authentic engineering learning environments

2 Leadership Paradox Compass

Engineering practice often requires navigating competing demands rather than choosing a single 'correct' response. Engineers may need to balance confidence with humility, innovation with reliability, or autonomy with alignment, often under conditions of uncertainty, time pressure, and shared responsibility.

The Leadership Paradox Compass (LPC) addresses this challenge by framing engineering leadership as a navigational practice rather than a fixed style, formal role, or set of prescriptive behaviours. At the level of action, the model focuses on how leadership becomes visible in everyday engineering decisions, team interactions, and trade-offs.

Consistent with the definition adopted in this chapter, LPC treats leadership as a learnable and transferable set of competencies and skills that emerge in how engineers interpret and respond to paradoxical situations.

2.1 Origin of the model

The Leadership Paradox Compass operates at the micro level of leadership development, focusing on judgement in action. It was developed to help engineering students and professionals navigate the complexity and competing demands of engineering practice.

The model draws on Elmore's (2021) concept of leadership paradoxes, which frames effective leadership as the ability to hold tensions rather than resolve them prematurely. To provide a structured behavioural framework, LPC also draws on the Leadership Practices Inventory (LPI) (Kouzes & Posner, 2003), which organises leadership practice into five established dimensions.

Table 2.5.2: Leadership Practices Inventory dimensions used in the Leadership Paradox Compass

<i>LPI dimension</i>	<i>Practical meaning in leadership practice</i>
Enable others to act	Building trust, collaboration, and autonomy so that others can contribute effectively and take responsibility
Encourage the heart	Recognising effort and achievement while providing emotional support and motivation
Inspire a shared vision	Creating and communicating a compelling direction that encourages collective commitment
Model the way	Demonstrating values through consistent actions, authenticity, and reliability
Challenge the process	Encouraging innovation, experimentation, and improvement in response to changing conditions

Table 2.5.3: Leadership paradoxes used in the Leadership Paradox Compass

<i>Paradox</i>	<i>Practical meaning</i>
Confidence and humility	Effective leaders combine confidence in decision making with humility to listen, learn, and adapt
Visibility and invisibility	Leaders need to be sufficiently visible to guide and support others, while also stepping back to allow others to contribute and grow
Teaching and learning	Leaders share knowledge and provide guidance while remaining open to learning from others
High standards and generosity	Leaders pursue excellence while balancing high expectations with empathy, patience, and support
Stubbornness and open-mindedness	Leaders remain committed to goals while staying receptive to alternative ideas and changing circumstances
Visionary thinking and detail orientation	Leaders balance strategic thinking with attention to operational detail, ensuring ideas remain both ambitious and achievable
Leading and serving	Leaders provide direction while also supporting the needs, growth, and success of others

The model is further informed by empirical analysis of LPI data from 240 participants in Poland, including leaders, non-leaders, and engineering students (Marjańska et al., 2024). Findings suggested that leadership development involves increasingly

differentiated and paradox-aware judgement, with some paradoxes spanning multiple LPI dimensions. Tables 2.5.2 and 2.5.3 present the leadership dimensions and paradoxes used in the model.

2.2 Description of the model

To visualise the Leadership Paradox Compass, we represent each leadership tension as a slider positioned between two competing but equally important orientations (Fig. 2.5.1). Rather than assuming that effective leadership always lies at one fixed point, the model encourages learners to explore how different situations may require different balances.

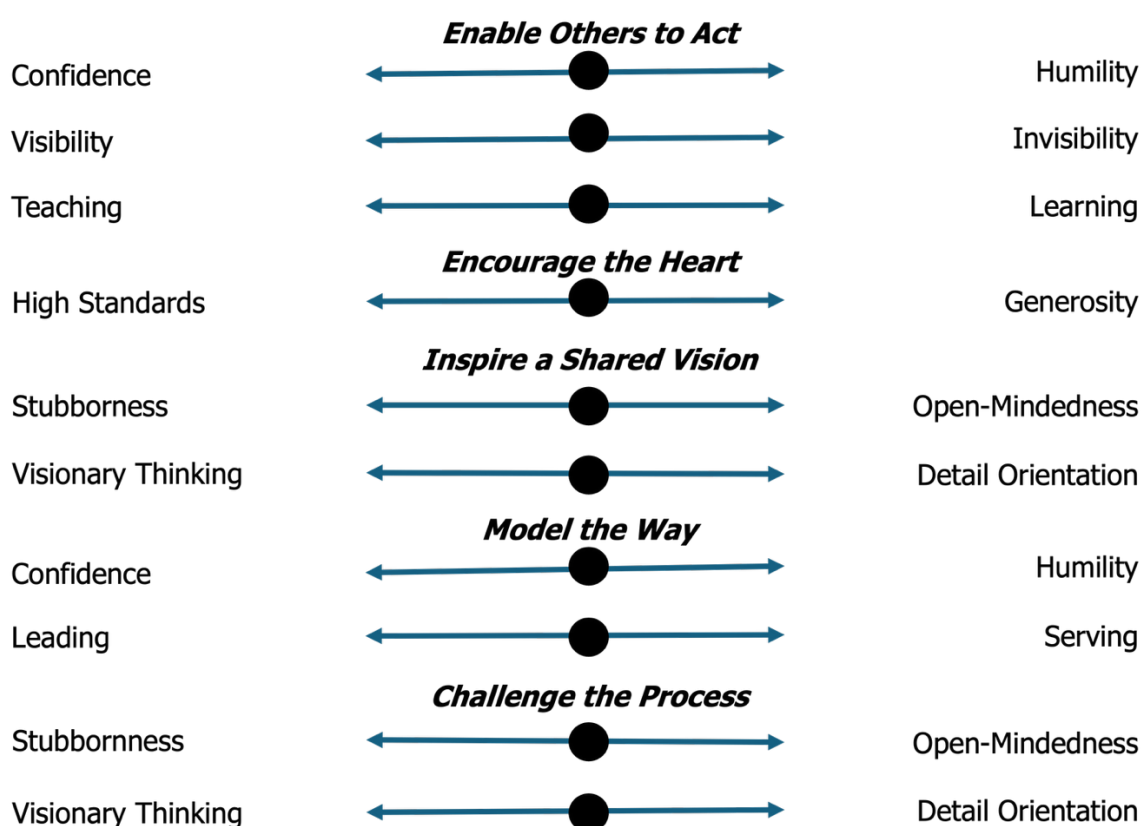


Figure 2.5.1: Leadership Paradox Compass: navigating tensions across five dimensions (elaboration by authors based on Elmore, 2021 and Kouzes & Posner, 2003)

Each paradox is linked to one of the five Leadership Practices Inventory dimensions described in Table 2.5.2. For example, supporting others effectively may require balancing confidence with humility, while innovation may require balancing visionary thinking with attention to operational detail.

The model is designed as a practical reflection tool. Educators can use it as a handout, discussion prompt, or team-based teaching aid to help learners analyse real

engineering situations, explore leadership tensions, and discuss how different responses may influence team dynamics and outcomes.

In Fig. 2.5.1, the markers indicate starting positions only. They are intended to be moved during reflection or discussion to represent how a particular engineering situation may shift the balance between competing leadership demands.

2.3 Application of the model

In educational practice, each paradox can serve as an anchor for reflection, discussion, and scenario-based learning. Rather than asking learners, *'What kind of leader are you?'*, the model encourages a more situational question: *'Which tension are you navigating, and how are you balancing competing demands?'*

This approach has been used in engineering education and leadership development activities, including classroom workshops and team-based project learning. It helps learners move away from viewing leadership as a fixed style and instead understand it as an adaptive practice shaped by context, relationships, and judgement.

One practical classroom activity involves asking learners to reflect on situations in which they supported others and situations in which they deliberately stepped back. Working in small groups, they analyse concrete episodes from team projects, identify which leadership paradoxes were present, and discuss how different responses influenced team dynamics and outcomes.

In our experience, this approach helps make leadership more tangible and relevant to engineering learners, particularly those who do not initially identify with leadership as part of engineering practice. By connecting leadership development to authentic team experiences, the model supports more intentional, reflective, and context-sensitive leadership learning.

Within the broader architecture presented in this chapter, the Leadership Paradox Compass complements the other models by focusing on leadership as enacted practice. It provides educators and learners with a shared language for reflecting on leadership-in-action and developing adaptive judgement in complex engineering contexts.

3 Engineering Leadership Orientations (ELO)

Many engineers continue to associate leadership with charismatic, hierarchical, or trait-based forms of influence, making it feel irreconcilable with engineering identity and practice. The Engineering Leadership Orientations (ELO) model addresses this challenge at the level of professional identity, helping engineers recognise leadership as a professionally relevant form of influence embedded in everyday engineering work.

3.1 Origin of the model

The Engineering Leadership Orientations (ELO) model was developed by Rottmann et al. (2015) through a mixed methods grounded theory study of leadership development in engineers' professional practice contexts. Drawing on survey and focus group data from more than 250 Canadian engineers working in four technically-intensive

organisations, the project team found that resistance to leadership decreased when leadership orientations were grounded in engineers' professional practice experiences. This professionally relevant model resulted in three compound engineering leadership orientations: technical mastery, collaborative optimisation, and organisational innovation (Rottmann et al., 2015). The orientations were subsequently tested using a 31-item survey with 175 Canadian engineers (Reeve et al., 2015). All three scales passed social science reliability thresholds (Cronbach's $\alpha \geq 0.7$) (Kline, 1999). This social science reliability measure indicates that the initial model, which was based on our qualitative analysis of small-scale focus groups, held up statistically with a larger sample of engineering professionals working in four different industries — software, mining, consulting, and chemical processing.

3.2 Description of the model

The ELO model suggests that engineers orient themselves toward leadership in at least three professionally grounded ways. Those with a technical mastery orientation support others through mentorship and sharing technical expertise. Those with a collaborative optimisation orientation strengthen team performance by mobilising expertise and fostering collaboration. Engineers with an organisational innovation orientation focus on strategic improvement, aligning technical work with broader organisational goals and future opportunities.

As illustrated in Fig. 2.5.2, when engineers associate leadership with hierarchical or charismatic stereotypes, they may resist leadership development. However, when leadership is framed as professionally relevant influence grounded in everyday engineering practice, many view leadership as consistent with their professional identities. This framing helps engineers see leadership not as a departure from engineering, but as an extension of sociotechnical engineering practice. These three compound orientations are not fixed personality types. Rather, they are dynamic approaches to leadership that shift across career stage, role, and organisational context.

3.3 Application of the model

The ELO model has been applied in undergraduate engineering classrooms (Moore et al., 2022; Reeve et al., 2014), co-curricular leadership programmes (Moore et al., 2021; Reeve et al., 2015), and professional development initiatives, including industry-sponsored leadership development programmes (Moore et al., 2025; Reeve et al., 2014). Across these contexts, it has provided an accessible entry point to leadership development by connecting it with engineers' professional identities.

A typical learning activity begins by asking participants to position themselves on a continuum ranging from '*Who, me? A leader?*' to '*Of course I'm a leader.*' This human continuum activity catalyses discussion about participants' assumptions, experiences, and relationships with leadership. Learners then complete an ELO inventory and use their results to reflect on their own orientations and team dynamics.

Because the model is grounded in engineering identity rather than abstract leadership theory, it can be particularly effective for learners who perceive leadership as

peripheral to engineering practice. It also offers a practical entry point for engineering educators who may feel hesitant to integrate leadership development into technically focused teaching.

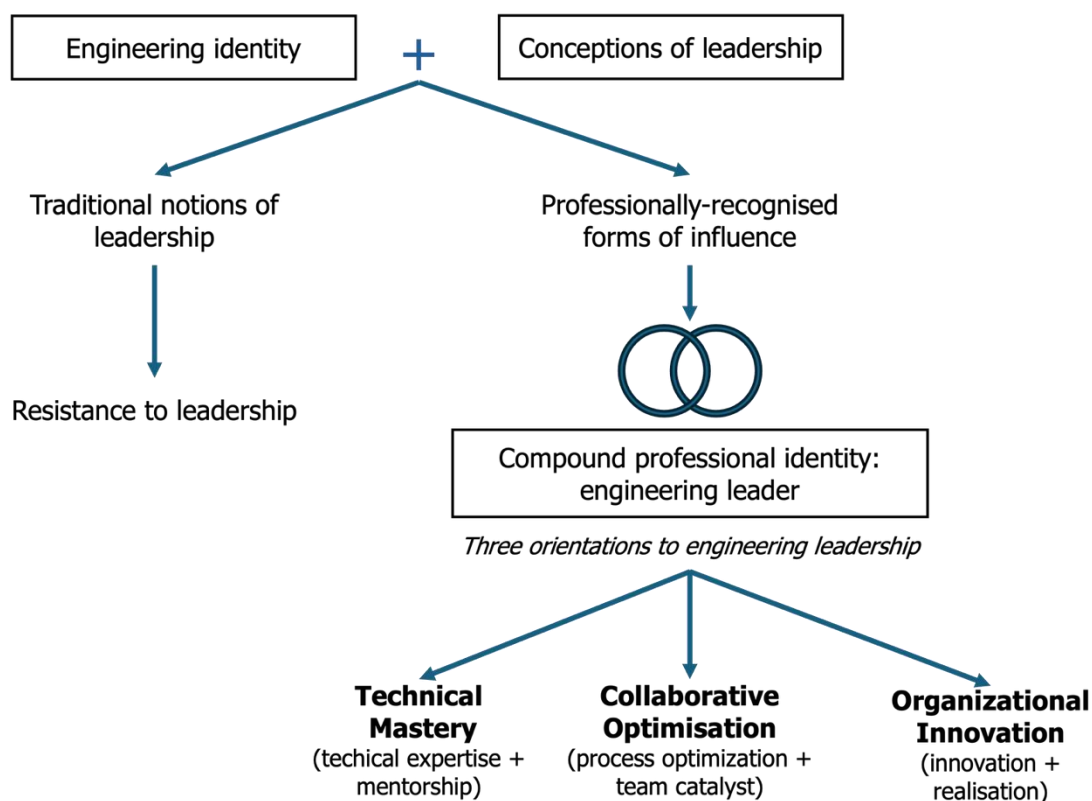


Figure 2.5.2: Engineering leadership orientations
 Exclusive rights by SAGE, published with permission — from Rottmann, et al. (2015). *Engineering leadership: Grounding leadership theory in engineers' professional identities. Leadership, 11(3), 351-373.*
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Engineering educators in Canada, the United States, Singapore, Australia, and other contexts have reached out by email to discuss how they may use the model in their own leadership development programmes, while growing numbers of engineering education students have approached me at conferences to indicate their intention to use the ELO model as a conceptual anchor for their research.

Within the broader developmental architecture of this chapter, the ELO model serves as a motivational bridge between leadership-in-action (LPC) and curriculum-level design (CELD), helping engineers engage with leadership development through professionally meaningful identities.

4 Contextual Engineering Leadership Development (CELD)

The Contextual Engineering Leadership Development (CELD) model focuses on how curriculum structures and learning environments shape leadership development within engineering education.

Developed in response to limitations in leadership development models commonly used in the United States, CELD takes an emergent engineering education perspective rather than adapting leadership theories developed in other disciplines. The model was designed to connect evolving definitions of engineering leadership with practical approaches to undergraduate leadership development.

4.1 *Origin of the model*

The CELD framework for undergraduate engineering education was developed by Kendall et al. (2018) through a qualitative study of four engineering programmes, supported by a literature review. The aim was to identify how engineering leadership development could be meaningfully embedded within engineering education rather than treated as a separate or externally imposed construct.

The analysis highlighted a teaching approach centred on reflective practice in four key areas: teamwork, engineering technical skills, contextual awareness, and effectual behaviour. These themes align with capabilities widely recognised as important for engineering graduates (Cox et al., 2012; Simmons et al., 2020), while offering a structured framework for leadership development within engineering programmes.

The four programmes examined in the original study shared a common ambition: preparing engineers capable of addressing complex sociotechnical challenges through innovative educational design. Although the institutional contexts differed considerably across programme types, institutional missions, and pedagogical approaches, they provided a useful basis for identifying transferable design principles for engineering leadership development. Representatives from each programme engaged in a structured reflective process, responding to common questions about programme design, leadership philosophy, and teaching practice. Through iterative comparison and thematic synthesis, the research team developed a shared framework for contextual engineering leadership development.

4.2 *Description of the model*

The CELD conceptualises leadership preparation as a set of concentric circles of expanding impact, as illustrated in Fig. 2.5.3. At the centre of the model, effectual behaviour emphasises self-awareness, awareness of others, and the ability to act despite incomplete information. It includes recognising knowledge limitations, seeking feedback, advocating for ideas, and adapting decisions as circumstances evolve. The second layer, teaming, positions leadership as a distributed and relational process rather than a formal role. Leadership in this context involves contributing to shared work, enabling the contributions of others, and creating conditions for effective and equitable collaboration. The outermost layer, contextual awareness, expands leadership beyond immediate team performance to the broader consequences of

engineering work. It encourages learners to consider the social purpose, ethical implications, and systemic effects of engineering decisions, recognising that technical work is always embedded within wider human contexts. Across all layers, engineering technical mastery remains foundational. However, the model explicitly rejects the idea that technical expertise exists in isolation. Technical competence is enacted through individual judgement, expressed through collaboration, and shaped by contextual understanding. Taken together, the model presents leadership development as a developmental process in which individual agency, teamwork, technical competence, and contextual responsibility become increasingly integrated as learners progress.

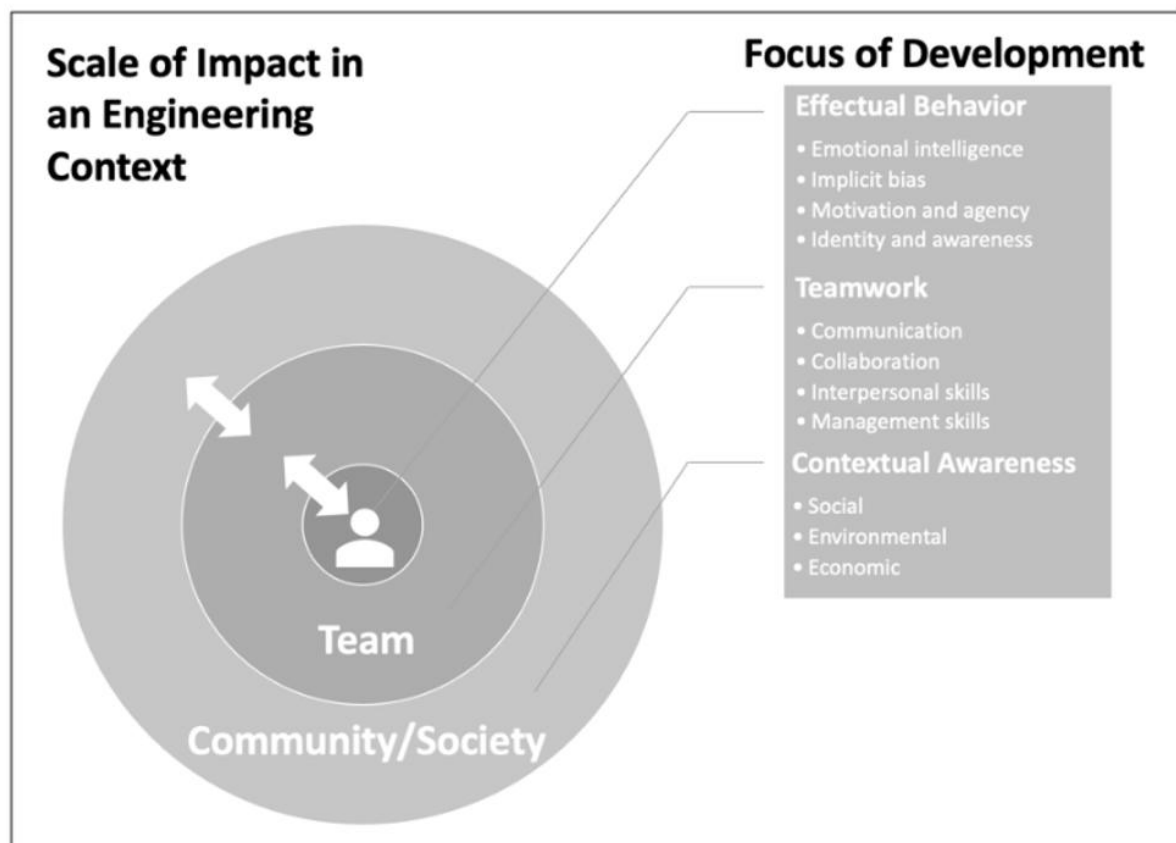


Figure 2.5.3: Contextual Engineering Leadership Development framework (elaboration by authors based on Kendall et al., 2018)

4.3 Application of the model

The CELD is grounded in educational practice and has been applied in multiple engineering education contexts. A detailed example of programme-level implementation is provided in the University of Texas at El Paso (UTEP) case study included in this book (See Chapter 4.10), as well as in Kendall et al. (2018).

A key strength of the model is its adaptability. Developed across diverse institutional contexts, it was intentionally designed to be transferable across different programme types, institutional missions, and pedagogical approaches. Although the original case

studies placed strong emphasis on team-based engineering design, the framework is not tied to any single instructional method.

The model can be applied at multiple levels, including individual learning activities, single modules, programme-wide curriculum design, and broader institutional leadership development initiatives. This flexibility allows educators to adjust the emphasis of leadership development according to learner needs, programme goals, and institutional context.

Although originally developed for undergraduate engineering education, there is emerging evidence of transferability to other contexts. For example, aspects of the model have been used in engineering faculty leadership development through the AMPLIFY Institute (Molano et al., 2023), and it currently informs a new Integrated Engineering Graduate Programme at UTEP. Related work is also underway to develop an instrument that helps learners and professionals identify their engineering leadership profile and support individual development planning (Campos Valles et al., 2025).

Within the broader developmental architecture of this chapter, CELD ensures that leadership development is not left to individual initiative alone but is intentionally embedded within engineering curricula and institutional strategy.

5 Cross-case summary of ELD models

Taken together, the three models offer complementary approaches to engineering leadership development. The LPC supports leadership-in-action by helping learners navigate tensions in engineering practice. The ELO model frames leadership as a professionally relevant dimension of engineering identity. The CELD framework embeds leadership development within curriculum design and authentic learning environments.

5.1 Points of convergence across the three models

Leadership as process. All three models frame leadership as purposeful influence enacted through engineering practice rather than positional authority or fixed traits.

Authentic engineering contexts. Leadership development is grounded in real engineering settings, including projects, teamwork, and sociotechnical problem solving, strengthening transferability and relevance.

Complexity and tension. Effective practice requires balancing competing demands, such as autonomy and alignment or rigour and adaptability, with LPC making these tensions explicit.

Relational and reflective practice. Leadership is collaborative, values-driven, and developed through reflection, shared responsibility, and interaction with others.

Adaptability across contexts. The models are flexible and can be applied across modules, co-curricular activities, and professional development settings.

Table 2.5.4: Practical guidelines for engineering educators across developmental levels (micro-identity-system) (Own Work)

<i>Model</i>	<i>Purpose</i>	<i>Learning outcomes</i>	<i>Activities or tools</i>	<i>Who are the learners?</i>
<i>Leadership Paradox Compass (LPC)</i>	To support reflection on leadership-in-action and paradox navigation in engineering practice	Recognise leadership tensions in engineering contexts; Navigate paradoxical demands. Adapt judgement to situational contexts	Structured reflection, scenario analysis, critical incident discussion	Engineering students, engineering practitioners in managerial roles
<i>Engineering Leadership Orientations (ELO)</i>	To support leadership identity formation in engineering	Identify and reflect on personal engineering leadership orientation; Generate strategies for collaborating across diverse orientations	Leadership continuum activity, ELO inventory, small-group reflection	Undergraduate students, mid-career engineers, graduate researchers in ELD
<i>Contextual ELD Framework (CELD)</i>	To align leadership development with curriculum-level engineering education design	Recognise contextual influences on engineering decisions; Develop interpersonal and teaming capabilities. Integrate technical expertise with values and agency	Team- and project-based learning, peer mentoring, integrated technical and transferable skills development, reflection and feedback	Undergraduate students, engineering educators

5.2 Practical implications

Engineering educators can combine these models according to local needs: LPC for navigating tensions in practice, ELO for professional identity development, and CELD for curriculum-level integration. Together, they position engineering leadership development as the parallel cultivation of technical expertise, relational competence, and contextual awareness in responsible engineering practice.

6 Implications and recommendations for EL development in engineering education

Before outlining practical recommendations, we summarise the primary purpose, learning outcomes, and applications of each model in Table 2.5.4. These models have been applied across engineering leadership development contexts in Poland, Canada, the United States, and beyond, including professional development, coaching, project-based learning, workshops, and structured reflection. Together, they illustrate how leadership development can be scaffolded across action, professional identity, and curriculum levels.

Regardless of the specific model or activity selected, our experience suggests several practical considerations for engineering leadership educators.

6.1 Consider learners developmentally and contextually

Engineering leadership development is most effective when aligned with learners' developmental readiness, prior experience, professional identity, and likely career pathways. Misalignment can reduce engagement and negatively impact leadership development.

As many (Chadha & Yeng, 2024) have noted in research on leadership development broadly, engineering leadership is more effectively developed when it is embedded within engineering practice. Otherwise, students may struggle to apply or recognise the value of the discrete topics being taught. By embedding engineering leadership development in practice, students are better able to connect the 'why' with the 'what' and recognise how both are necessary in professional practice.

Learning opportunities should also reflect learners' financial, social, cultural, and institutional realities while preparing them for diverse professional environments. Furthermore, understanding students' cultural context is necessary, as it helps instructors tailor content to align with students' assumptions and beliefs about leadership, while also opening opportunities for them to consider alternative ways of leading. It also provides an opportunity for instructors to prepare students for leading in different societal structures and pressures, such as those related to gender, ethnicity, race, or ability.

Example 1. System-level design: curriculum, assessment, and institutional capacity (CELD). The power of alignment between students' prior development and learning activities

At UTEP, in the context of our undergraduate Bachelor of Science in Engineering Innovation and Leadership programme (BSEIL), many of our students have well-developed identities as leaders by the end of their first year. As a result, we have received considerable feedback from students on how we have implemented the Student Leadership Challenge (student focused materials developed by the authors of the Leadership Practices Inventory (Kouzes & Posner, 2003)) materials throughout our program. In Year 2, many students reported feeling that the leadership activities were designed for high school students, rather than college students, and that they wanted something deeper and more realistic. They recognised the value in the activities, but were reporting a misalignment with their development level, which motivated a shift in our programme to develop custom materials that better connected to students' development level.

6.2 Consider how you frame leadership

Students bring prior assumptions about leadership into the classroom. The way in which leadership is introduced can strongly influence engagement and openness to development. We recommend that instructors who are seeking to situate leadership learning in their classroom:

- Start with visible leadership behaviours such as taking initiative, role modelling, or constructive team contributions.
- Frame leadership as purposeful action by connecting behaviours to meaningful engineering outcomes.
- Design for experimentation through low-risk formats such as simulations, labs, and iterative project work.
- Encourage peer recognition to make informal leadership contributions visible.
- Connect vision to practice by linking ambitious ideas to practical engineering action.
- Use paradoxes as interpretive tools to help learners explore tensions rather than seek simplistic solutions.

6.3 Be intentional about learning goals

Not every element of a model needs to be addressed in a single module or activity. What matters is that learners can situate individual experiences within a broader leadership development framework. Clear, measurable, learner-centred learning objectives help educators prioritise what is developmentally realistic and pedagogically meaningful. In many cases, focused developmental goals are more effective than attempting to address leadership development too broadly at once.

Example 2. Micro-level design: embedding leadership-in-action (LPC): Paradox navigation in Lean improvement teams at Gdańsk University of Technology

In a Production Management module, student teams analyse manufacturing processes and propose Lean improvements (e.g., waste identification, quick PDCA experiments). After each intervention, teams run a 10-minute LPC debrief:

individually, students place markers on the most salient paradox sliders (e.g., confidence-humility, high standards-generosity, leading-serving, open-mindedness-stubbornness); they then explain their choices and agree on one concrete adjustment for the next cycle. This short, visual routine helps students connect technical decisions to team tensions they have actually experienced — when they prioritised speed over rigor, who spoke versus who stepped back, and how they balanced teaching versus learning while dividing tasks. Instructors observed that early iterations skewed toward control and ‘getting it right,’ while later cycles showed more Enable Others to Act behaviours (delegation, autonomy) and open-mindedness (trying rival ideas). Students reported clearer expectations about soft skills, faster consensus, and more constructive conflict because the LPC gives a shared language for the trade-offs embedded in engineering work. A transferable insight from this example is to embed brief LPC debriefs inside authentic technical tasks and repeat them across iterations — the combination of action and reflection normalises paradox thinking and turns ‘style disagreements’ into targeted team adjustments.

6.4 Design for engagement, practice, and feedback

Engineering leadership development is most effective and credible when empirically derived theories are connected with personal and professional practice. Dialogue, collaboration, and reflection on theoretical models often promote engagement among students who already view themselves as leaders, but these pedagogical strategies may not work as well for engineers who view their identities as primarily technical. One way to support leadership development in the latter group is to expose them to engineering leadership inventories, and other forms of personally and professionally meaningful assessment. Tools for assessment vary widely, including rubrics to facilitate peer assessment, self-assessment questionnaires, written reflection assignments, or 360-degree assessments (Novoselich & Knight, 2022). We describe one such tool in the example below.

Example 3: Professional identity development: ELO inventory

At the University of Toronto, Canada, we introduce students and professionals to the ELO model by asking them to complete a 15-item inventory derived from a subset of survey items with high factor loadings. We generated two inventories — one geared to professionals and the other adapted for students. The inventories allow participants to explore their own leadership orientations, connect with others who have similar orientations to examine their strengths and weaknesses, and pivot to other orientations when necessary. The questions are easy to answer, and the inventory is set up for self-scoring, making it an accessible entry point for students and professionals who may not see themselves as leaders. The ELO inventory provides engineers with conceptual anchors related to their own leadership orientations, but like any other pedagogical tool, we needed to actively help participants make sense of the ways these conceptual anchors are tethered to their everyday lives and organisational contexts. The inventory is not proprietary but is

minimally useful on its own. We encourage interested engineering educators to help their students connect theory to practice by reading the original article (Rottmann et al., 2015) and reflecting on their orientations in project team and organisational contexts.

6.5 Consider educator and institutional capacity

Engineering leadership development depends not only on learner needs, but also on educator expertise, available resources, programme culture, and institutional context. Educators may require upskilling when adopting unfamiliar pedagogies such as project-based learning, coaching, or reflective practice, while institutional realities shape what is realistic and sustainable. Programme resources and institutional culture strongly shape decision-making. Resource availability is a key factor. For example, new programmes may have initial funding and excitement but lack alumni networks or a reputation, making it harder to invite guest lecturers or external speakers than established programmes. Institutional mission also matters — leadership programming at a military institution or in veteran-focused programme will naturally differ from that at an agriculture-focused institution, even with similar learning outcomes. Alignment between leadership activities, educator capacity, and organisational context increases the likelihood of long-term success.

6.6 Resources and further reading

In addition to the literature referenced in this chapter, we also suggest *Leadership agility: Five levels of mastery for anticipating and initiating change* by Joiner and Josephs (2006) and *A model of empathy in engineering as a core skill, practice orientation, and professional way of being* by Walther et al. (2017).

7 Conclusions

Together, the Leadership Paradox Compass, Engineering Leadership Orientations model, and the Contextual Engineering Leadership Development framework offer a coherent, multi-level approach to engineering leadership development that connects educational practice with professional engineering realities. The models position leadership not as an appendage to technical education, but as an integral part of engineers' professional formation. They frame engineering leadership as relational, contextual, reflective, and embedded in sociotechnical practice, while offering complementary tools across action, identity, and curriculum levels.

This chapter reinforces a central message: transferable leadership capabilities are essential to responsible engineering practice.

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AI statement

During the preparation of this work, the authors used ChatGPT 5.2 to make linguistic corrections and edit text fragments. After using this tool, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

Contributor statement

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2.6

Teamwork

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Keywords: *teamwork, team skills, team dynamics, transferable competencies and skills*

While teamwork is considered one of the core transversal competencies expected from engineers and is widely implemented in engineering education, educators often have limited exposure to knowledge of team dynamics and processes, which can make it challenging for them to set up effective team-based learning. In this chapter, we discuss the knowledge, skills, and attitudes required for students to perform teamwork effectively. We dive into various team processes, such as action-oriented behaviours and emergent states that are built through interpersonal interactions during teamwork, which are crucial for functional and effective teams. Building on conceptual foundations, we provide educational examples on how to form and support student teams and how to provide training in conflict management. The chapter also lists our recommendations for setting up teamwork-based learning, forming teams, and managing teams, especially when teams experience problems. We share a concrete teamwork session lesson plan as an inspiration source for educators who struggle with incorporating a teamwork-themed workshop into their modules.

1 Teamwork: a complex core engineering competency

Teamwork is a core engineering competency for adaptive, creative work, especially to solve interdisciplinary, complex issues beyond an individual's ability (Salas et al., 2008). Teamwork refers to the coordinated actions of two or more individuals — such as communication, decision making, and task coordination — to achieve a common goal (Driskell et al., 2018). Teamwork effectiveness refers to the degree to which team results satisfy the expected requirements or expectations (Essens et al., 2008) and usually includes attitude, behavioural processes, and performance (Wang et al., 2014). In this chapter, we use teamwork as an umbrella term and do not distinguish between related terminologies, such as groupwork, collaboration, and cooperation (for a reference to this distinction, see the references and further reading section).

1.1 Teamwork competencies – knowledge, skills, and attitude (KSAs)

Teamwork competencies are comprised of a series of interconnected knowledge, skills, and attitudes (KSAs) that enable effective coordination and collaboration (Nadal et al., 2015). Examples of teamwork-related KSAs are listed in Fig. 2.6.1. Skills, which are often intertwined with knowledge, involve the ability to enact the strategies and perform the tasks in practice. Attitudes such as openness, a sense of responsibility, willingness to adapt roles, and valuing diverse perspectives are essential for effective, high-performing engineering teams.



Figure 2.6.1: Teamwork-related knowledge, skills, and attitudes
(Own Work by Éva Kalmár, 2026)

Team competency frameworks, in general, list what professionals should be competent to do. For example, the CDIO framework highlights that engineers should be able to 1) *work in teams*, which covers aspects like team formation, setting goals, planning the project and scheduling tasks, setting team norms, coordinating and managing team processes, making choices about team leadership and membership, handling conflicts, supporting individual and team creativity, motivating team members, and finally, assessing the process and the outcome through reflection; 2) *engage with stakeholders*, co-create with them; 3) *manage multi-perspective* and multi-, inter- and transdisciplinary *collaborations*; and finally 4) *establish* diverse connections and *networks* (Crawley et al., 2014). Other frameworks utilize different taxonomies to categorize teamwork-related KSAs, such as 1) conflict resolution; 2) collaborative problem solving; 3) communication; 4) goal setting and performance management; and 5) planning and task coordination (Stevens & Campion, 1999); or 1) identifying team membership and role; 2) establishing productive relationships; 3) meeting team objectives, and 4) resolving conflicts (Leslie, 2016). *Regardless of the framework that you decide to use, it is important that you select and adapt one, as students will benefit from explicit support in understanding the aspects and competencies of teamwork.*

1.2 Relation to other skills

Task-related, interpersonal, and reflective competencies have been shown to significantly influence individuals' capacity to foster team effectiveness and performance and enhance team dynamics (Jalali et al., 2022). Some of these are discussed in detail in other chapters of this handbook.

Interpersonal skills, such as open dialogue, empathy, active listening, information sharing, and participation, are foundational to effective teamwork (Jalali et al., 2024; Stevens & Campion, 1999). As conflict is a normal aspect of teamwork, helping our students understand how to sustain collaboration through the common teamwork setbacks can help them develop these skills more effectively. Therefore, conflict resolution and negotiation skills are essential to help student teams distinguish productive disagreement and constructive feedback from destructive conflict.

Furthermore, the ability to step back, think critically, and reflect on specific situations, and particularly on how students perform, is essential for learning and skill development (Isaac et al., 2024). The meta-cognitive perspective, *including individual and group reflections*, is crucial for developing self-awareness and team awareness. Reflection allows students to evaluate their contribution, understand team dynamics, and plan for future improvement, but more importantly, it can have a huge influence on how they perceive teamwork and their attitudes for the future.

2 Teamwork competencies need facilitation

Teamwork competencies are widely recognized as core transversal competencies in engineering education because of the inherently collaborative nature of engineering practice and due to accreditation requirements, industry expectations, and the growth of team-based and project-based learning (Borrego et al., 2013; Felder & Brent, 2024;

Prince & Felder, 2006; Trevelyan, 2019). *However, simply placing students in teams does not ensure that they will develop strong teamwork abilities* (de Prada et al., 2022). In other words, teamwork-related KSAs must be explicitly included as learning outcomes, and the modules must be intentionally designed to support the development of these KSAs through theoretical grounding and opportunities for practice, feedback, and reflection on students' experiences (Borrego et al., 2013).

We can learn a lot about facilitating team-based learning from student-reported teaming experiences. Their positive experiences with teamwork typically involve clear communication, the value of building personal relationships, and the sense of satisfaction derived from what they accomplished. Without intentional design, student teams frequently experience negative outcomes traditionally associated with teamwork, even developing an attitude against teamwork. Negative experiences often are associated with role ambiguity, interpersonal conflict, and uneven contributions (Wolfe et al., 2016), which could lead to dysfunctions in student teams (Wei & Han, 2025). Often, students do not interpret teamwork through contextual lenses or social structures (e.g., they do not reflect on their previous teamwork experiences, how they perceive the value of a task or the usefulness of the teamwork project), although these factors shape their attitudes and engagement in the team effort (Tucker & Abbasi, 2016; Wei & Han, 2025).

Designing engineering programmes that support teamwork is itself a complex challenge. Educators must understand what effective teams and healthy team dynamics look like and when to prevent conflict that becomes destructive while encouraging productive collaboration. This can be challenging when educators do not have the theoretical foundations. Conceptual frameworks on team effectiveness, particularly *input-process-outcome (IPO) models*, are useful to rely on. The IPO models highlight the intricate relationships between three crucial components: inputs, processes, and outcomes (Marks et al., 2001). Within educational settings, inputs refer to factors such as team composition, task complexity and structure, and other factors, such as the length of the project. Processes encompass how teamwork is performed, including team member interactions, communication, and task coordination. Finally, outcomes include the results of collaboration, such as the quality of deliverables (reports, presentations, artefacts), individual satisfaction with team membership, and the impact of teamwork on individual development.

A key strategy to develop strong team-based learning environments is to focus on the team processes over time, especially team emergent states—conditions such as team efficacy, collective confidence, shared mental models, and psychological safety, that arise through interaction and experience. Modules supporting the development of teamwork competency have to support the development of emergent states at the early stages of teamwork (Ilgen et al., 2005). These early interventions aim to promote discussions on students' understanding of the project, information seeking and sharing, feedback, and interpersonal communication, which lead to shared understanding, shared team mental models, and team goals (Marks et al., 2001). Team members' feelings, emotions, and attitudes are crucial in creating these

emergent states and have a relevant effect on whether students trust each other and believe that the team can reach its common goal together (Collins & Parker, 2010).

As a practical introduction, a simplified Tuckman and Jensen (1977) model on *team phases* (forming, storming, norming, performing, adjourning) can help students understand team development, while instructors normalise early struggles and intentionally support motivational and interpersonal dynamics, so teams move more effectively toward norming and performing.

To support student teams to become effective and well-functioning, educators need to invest in explicit instructions that equip students with the necessary tools and strategies, and they should create opportunities for reflection and feedback. In engineering education settings, while repeated opportunities for practice and feedback on the process of creating solutions are increasingly accepted, deliberate and explicit instruction related to teamwork processes, especially those that focus on emergent states, remains the exception (Borrego et al., 2013).

3 Forms of implementation

What criteria should guide team formation? How can we ensure that teams reach their full potential? In what ways can we support individuals in developing their capacities and acquiring teamwork competencies? How should challenges encountered during the teamwork process be addressed?

We believe that educators who are willing to set up team-based learning experiences need to be acquainted with teamwork theories and have a palette of possible methods to choose from to answer these pressing questions.

In the following sections, we present two case examples, recommendations and a template for a teamwork workshop that reflect and illustrate essential features and practices of effective teamwork, facilitating the development of teamwork skills. Our intention is not to provide ready-to-use solutions, but instead, sources of inspiration that can be modified to context-specific educational methods and materials.

Example 1. Forming effective teams: a case from TU Delft

It is common and beneficial for students to select their own teams because it can increase their commitment to solving a problem, resulting in more intrinsic motivation. However, such practice can result in a lack of within-team diversity, which has a huge effect on the team's transactive memory system — the knowledge represented by all team members (Kozlowski, 2018), affecting transdisciplinary learning (MacGregor, 1990), collaborative learning (Curşeu & Pluut, 2013) and the creativity of the teams. Setting up teams according to predefined diversity criteria is crucial for effective team learning. While homogenous teams tend to experience less team conflict, they also learn less, in general, because they do not challenge each other's worldviews, decisions and solutions. This also results in less creative outcomes.

In the Collaborative Science for Biomedical Breakthroughs (CSBB) interdisciplinary Nanobiology minor programme organised by TU Delft and Erasmus MC in the Netherlands, setting up teams is done by the minor coordinators based on students' topic preferences, gender, domain background, and team role preferences (Colgrove et al., 2025). This method of setting up teams gives students autonomy to maintain their interest-led, intrinsic motivation, while the coordinator ensures that all teams remain diverse and effective.

During the first weeks of the CSBB minor, students participate in sessions that facilitate individual and team reflection competencies, and they actively participate in various team formation exercises. First, they play biology-related board and card games to get to know each other and to create fun memories. Playing games can facilitate the creation of a team climate that supports playful experimentation and failure, instead of focusing on grades. When playing games, students can determine their own path (which gives them a high level of autonomy); they can engage with the game just for the sake of exploration, which stimulates experiential learning; they expose themselves to a series of surprises, which teaches tolerance of uncertainty; it fosters their imagination; and welcomes foolishness which boosts creativity (Gudiksen & Skovbjerg, 2020). By playing games during the team formation stage, students get to know each other outside of the challenge context.

A few days after playing games, students attend a workshop dedicated to mapping the teams' transactive memory system. In this workshop, each team member writes down on transparent plastic foil pieces their areas of knowledge, skills, methods used when approaching a problem, values, and finally, their emotions. Then, they discuss the various items by placing the transparent foils on top of each other, as shown in Fig. 2.6.2.

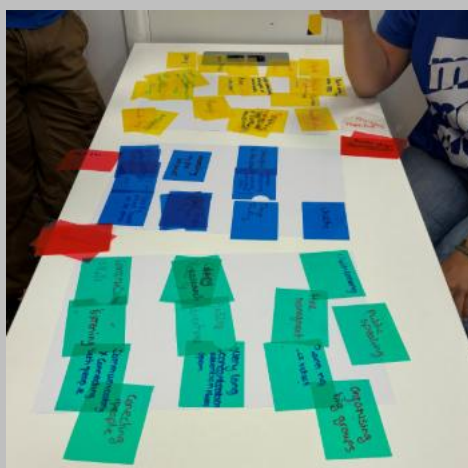


Figure 2.6.2: Demonstration of activity to map the team's transactive memory system at the CSBB minor (Own Work by Éva Kalmár, 2025)

Students are encouraged to discuss the potential meaning of the overlapping areas and the distance between various elements. As this workshop requires reflective

metacognitive thinking, it is advised to incorporate sessions on individual reflection and a lecture on various knowledge types before this session. This mapping activity can be used to analyse the various domain knowledge each member brings to the team, to articulate whether they miss certain knowledge, skills, or team roles, and the goals, needs, and characteristics (work styles, cultural differences) of individual team members. Finally, this activity can lead to the creation of the team's common values and norms and define the first draft of the team's ground rules.

Example 2. Facilitating experiential learning in cross-cultural teams to develop intercultural and teamwork competency together — a case from Purdue's global engineering module

We redesigned the required one-credit Global Engineering Orientation module at Purdue University, USA, for study-abroad students to better develop intercultural and teamwork competencies together. The earlier version focused mainly on individual learning and reflection about cultural theories, but the revised module added team-based intercultural activities and a 50-minute teamwork training session before team assignments. Because teams were primarily formed by study-abroad destination, the training emphasised practical teamwork processes that students could apply immediately.

The training session primarily focused on identifying roles in teams and conflict resolution. We first presented a variety of possible team roles based on the "Teamwork Foundations" video via LinkedIn Learning (Croft, 2020), which helped students to operationalize the teamwork input with tangible resources to enact. Then, we asked students to select two or three preferred roles based on their personal strengths and previous experiences, as well as two to three roles to avoid and other possible candidate roles. After individual selection, students shared their choices with the team. We then promptly introduced the concept of team conflict to students and emphasised that there existed constructive conflicts to improve the quality of teamwork and its product. Afterwards, we shared five styles of conflict management (Thomas & Kilmann, 1976) and videos on how to conduct crucial conversations to facilitate informative and productive communication (Effective Team Dynamics at GT, n. d.). With this setup, we then invited students to discuss with teammates how to negotiate individual team roles. This discussion allowed students to practice and reflect on conflict resolution and interpersonal communication, which are crucial for effective teamwork dynamics.

Cross-cultural reflections as a part of the module assignment, anchored in cultural differences, reinforced teamwork learning (Hofstede et al., 2010). Students first reflected individually on cultural barriers and created personal work plans, then collaborated on a team essay examining cultural similarities and differences and on a shared teamwork plan. Finally, they wrote an individual reflection on strategies that helped their cross-cultural team communicate and work effectively.

4 Recommendations for implementing and learning

In this section, we present several recommendations you can use to implement team-based pedagogy and develop teamwork competencies within your classroom environments. Our aim is to support setting up such team-based learning environments prior to the module starting, connecting the theoretical insights present in the previous chapters with hands-on advice. We also included how to handle dysfunctional teams during the process.

4.1 When developing teamwork-based education

Do not use teamwork just because this decreases the amount of feedback and grading time. Choosing team-based education has consequences for student learning, and if not done properly, it can cause more harm than good (Felder & Brent, 2024).

It is also critical not to assume that students naturally develop teamwork skills simply through group work. Consider making teamwork-related KSAs an explicit part of your learning outcomes, supported by thoughtful and targeted activities with clear instructions. The CDIO framework provides examples of *teamwork-related learning objectives* (Crawley et al., 2014). Highlighting the goal of these activities can help students who want to immerse themselves in the module content as soon as possible and spend some time on these activities. Be prepared that students might see these activities as irrelevant at the given time point for the project context and only appreciate them after the end of the module.

We suggest thoughtfully reflecting on specific frameworks of teamwork when designing instruction aimed at developing teamwork competencies. There are multiple frameworks available; just pick one that aligns with what you need and follow it. Finally, consider adopting a more systematic approach to teaching teamwork competencies. For example, we recommend the Trident Framework proposed by Isaac et al. (2024), which outlines three dimensions for teaching transversal skills: knowing, experiencing, and learning from experience.

4.2 Team formation

For the best team learning experience, teams of three to four are ideal, although teams of two to six students could also work fine, depending on the project context and complexity (Felder & Brent, 2024). Teams that are too large are more likely to face problems such as free riding, domination, and scheduling difficulties, while teams that are too small may lack enough diversity in skills and perspectives and can be more easily dominated by one member (Wankat & Oreovicz, 2015).

We recommend instructor-formed teams — especially when teamwork is a module learning objective — rather than relying on self-selection or random assignment. Digital tools like CATME (Purdue University, n.d.) can support team formation (the Team-maker survey takes lecturer's criteria into account when generating teams) and peer evaluation (the Peer Evaluation survey filled in by students can highlight team challenges), particularly in large classes. When forming teams, instructors should distribute students' abilities and experiences (e.g., language proficiency and

computer, technical, and hands-on skills), avoid isolating minority students in early-year modules (Felder & Brent, 2024), and ensure teams have a common time to meet outside class to reduce scheduling-related conflict.

To help you form teams, collect students' past teamwork experiences either by a brief pre-module survey or by asking them at the first team session. In addition, implement a team-building activity in class when the teams are announced, so students can get to know each other in a structured way to build psychologically safe environment (Ilgen et al., 2005). We advise playing (serious) board, card, or other types of games, potentially related to the topic or the case of the module, as mentioned in Chapter 2.1 (see Land, 2019). Also plan an activity when the teams create their team contract that includes their individual and team goals, roles and responsibilities, chosen ways of communicating with each other, and conflict resolution strategies.

In addition, suggest a social activity for the teams and highlight the importance of social-emotional interactions, besides task-oriented interactions. These activities are essential for the emergent states. Finally, explain the importance of developing teamwork competency and the importance of check-ins and accountability during the semester.

4.3 Team operation

During the module, design a session when students can learn and practice effective communication (active listening, collaboration, providing and obtaining information, and feedback). Also create a session when students can learn about various types of conflict resolution styles and provide them with possibilities to practice these (Magana et al., 2022).

Peer evaluation and feedback are well-established strategies for developing teamwork competencies in engineering education (Donia et al., 2018; Loughry et al., 2014.). We recommend web-based tools that let students evaluate peers and themselves using clear criteria tied to contributions and teamwork behaviours. Regular structured feedback and reflection improve students' confidence and skill in giving feedback, increase rating quality, and support teamwork learning (Donia et al., 2018; Loughry et al., 2014). As Felder and Brent (2024) note, peer evaluation should primarily promote cooperation, responsibility, and commitment — not just add another performance rating — so instructors should distinguish between items assessing task skills and those assessing interaction quality and teamwork commitment.

Beyond the formal peer evaluation, deliberately build in chances for students to reflect on their team process — what's working, what needs attention, and whether the original plan should change. This can be supported through assignments or in-class activities such as 1) creating and revising a team charter or code of cooperation; 2) writing individual reflections on collaboration; and 3) completing an individual contribution log that quantifies each member's contributions as percentages.

4.4 Team dysfunction tactics

Module design strategies suggest that forming balanced and evidence-based teams, conducting self- and peer evaluation, setting clear expectations, monitoring team dynamics, and cultivating a culture of psychological safety in teams are all effective means to circumvent team dysfunctions, such as social loafing or free riding, marginalisation, lack of team consensus, and lack of accountability. Besides those suggestions, the following approaches are helpful to avoid the frustrations caused by malfunctioning teams:

- In addition to a teamwork training workshop, require student teams to draft a team charter signed as the governing document to co-regulate the process.
- Provide opportunities for the teams to explicitly articulate everyone's contribution and set the expectation that individual scores could be reduced if not contributing enough, or at all.
- Reinforce periodic peer evaluation feedback as both a formative assessment for improvement and a summative assessment to adjust individuals' grades multiple times, especially in the early stage.

There are two main factors to consider: 1) if there is time for student teams to improve, and 2) if the situation is serious enough that it needs immediate, radical interventions. When time permits, we want to give all students a chance to improve, but there are a series of staged strategies that can be helpful to calibrate the team dynamics:

- Private instructor check-in with the whole team to solicit the team dynamics and contribution distribution and invite students to reflect on previous strategies and ways to balance workload.
- Lead a 'reset' meeting to revisit team charter and help establish a workable workload distribution, role clarification, and a concrete milestone, as rescope will be helpful. When necessary, provide tutoring and counsellor resources for additional support.
- If the team is given time and feedback to improve but this is not working, collect evidence and triangulate narratives across the entire team to inform judgement for grade differentiation. Provide a bonus for overloaded individuals and assess a penalty for free riders.
- As a last resort, remove the free rider from the team project pathway and set an alternative individual pathway if feasible.

Example 3. Example teaching material: an introduction to teamwork session for engineering modules

This example provides a complete resource that you can modify to your educational context at the beginning of a project or module. It draws on established findings from the teamwork literature, as well as our collective experiences teaching teamwork. You are encouraged to adapt the timing, examples, and activities to your own context. The language below is descriptive, directive, and rich in example phrases, allowing you to adapt. The recommended length of the session is 80

minutes, but it can be compressed to 60 or expanded to 120 minutes. Fig. 2.6.3 shows the overview of the lesson plan.



Figure 2.6.3: Lesson plan for teamwork (Own Work by Éva Kalmár, 2026)

Lesson plan for teamwork workshop

1. Opening reflection: "Good vs. bad team" (10 minutes)

Materials:

Slide "Think about your best/worst team", sticky notes, shared document, prompt cards.

Open by stressing that we expect teamwork but rarely teach it well. Use this moment to outline the semester project and expectations, then focus on students reflecting on prior team experiences, using their stories to avoid repeating past failures.

Student tasks:

- *Individually (1 minute): write an example that describes a positive team experience and a negative one. Alternative option: write three words or short phrases that describe a positive team experience and three that describe a negative one.*
- *Share with your neighbour or group (3 minutes): cluster common ideas — what patterns emerge?*
- *Whole class (5 minutes): invite volunteers to share one 'good' and one 'bad' pattern. Capture these visually on a whiteboard or slide.*

Have students identify recurring teamwork patterns so they can reinforce the positive ones and plan strategies to prevent negative ones. As themes like free

riding, psychological safety, and communication emerge, use them to launch a discussion about the behavioural side of teamwork and the importance of individual contributions.

2. Mini-lecture: why teamwork? (8 minutes)

Materials: *slides*

Key talking points:

- *Engineering work is increasingly interdisciplinary, and employers expect graduates who can collaborate effectively. Have students review job ads for their 'dream job' or provide industry examples and identify how teamwork is emphasised.*
- *High-performing teams generate synergy: the result is greater than individual contributions. Low-performing teams drain energy and time.*
- *Students rarely receive explicit training in team processes; we're making that training visible and assessable.*
- *This module will evaluate both your product and your process. Process evidence (charter, meeting notes, peer feedback) matters.*

Suggested slide visual: statistics on the time engineers spend collaborating, or a quote from industry partners emphasising teamwork.

3. Defining team vs. groups (7 minutes)

Materials: *definition slide; reflection on impact*

Have students work in their teams; ask them to establish characteristics of a team vs. characteristics of a group. Have them pick examples and share with the class. Have a discussion and agree as a class on what entails a team vs. a group.

You are in charge of summarising: groups coordinate logistics and split tasks; teams share a purpose with interdependent roles and collective accountability. Teaching this distinction matters because it shapes students' expectations, behaviours, and definitions of success — and helps them navigate many kinds of collectives beyond high-interdependence project teams.

4. The Effective Teamwork Model: definitions and mini-activities (10 minutes)

Materials: *model slide; handout summary*

We encourage instructors to select a teamwork model and present it. We have used the Effective Teamwork Model (Adams, 2002), but instructors can select the teamwork model of their preference. The important aspect here is to have a model that comes from the literature and has been implemented and validated in the past. Spend the time describing and presenting the model to the students.

Note: some instructors may present the model after the team-building activity; that may work too. We prefer introducing it beforehand, running the activity, then

debriefing by linking experiences back to the model — since students often omit key elements even when they know the framework.

Activity hook: “as I describe each element, jot down one behaviour your team could adopt to make that element come alive.”

5. Experiential activity: the Marshmallow Challenge (20 minutes)

Include an early hands-on team-building activity so students meet their teams and start collaborating right away. Use a fun, low-stakes challenge (e.g., the Marshmallow Challenge — building the tallest free-standing structure from spaghetti, tape, and string, with a marshmallow on top) that encourages creativity and risk taking, then have teams analyse their process against the model.

Instructor notes: run a countdown timer and circulate to observe behaviours (leadership, idea vetting, and conflict points).

6. Debrief: connecting experience to the model (15 minutes)

Materials: guiding questions on slide or handout

The debrief is essential: it links the experience back to the teamwork model and makes students notice real team behaviours. In the Marshmallow Challenge, many students say it feels different when the activity is framed and analysed explicitly. A useful comparison is that kindergarteners often outperform engineering students (Furr, 2011), likely because they have higher psychological safety in taking risk and prototype early with the marshmallow (the real constraint) in mind.

Guiding questions (display or read):

- How did you start? Did you plan first, or jump into building? What were the consequences?*
- Where did communication work well or break down? Any examples of active listening?*
- Did roles emerge? Were they explicit? How did that help or hurt?*
- Describe a moment of disagreement. How was it handled?*
- Did everyone feel safe proposing ideas or pointing out problems? Why or why not?*
- Another option is to have students fill out a short reflection on the activity.*

It is very important to map some of those moments to the teamwork model. Which element was strongest for a team? Which needs work? Have the students capture one improvement they will carry into the real project.

7. From concept to commitment: drafting the team charter (10 minutes)

Materials: charter template; role cards

Take the opportunity to have the students draft a team charter, contract, or similar. Explain that a charter is not busywork. It’s their team’s contract: how they will work, decide, communicate, and hold each other accountable. Explain that they will revisit it when things get messy. Emphasise that conflict is a normal part of life and we

should not avoid it; rather, we should have strategies in place to solve it productively. Here, instructors can bring the importance of individual preparation and contributions (Arthur et al., 2025).

8. Sustaining teamwork: follow-ups and assessment

Materials: *timeline slide; rubric excerpt*

Suggested checkpoints:

- *Process check 1 (Week 3): 5-minute anonymous form rating each model element; teams adjust charter accordingly.*
- *Midterm peer feedback (formative): short rubric-based feedback on contributions and communication. One example is to develop a survey where each team member will divide €100 among team members (including themselves) based on contributions. Analyse the data and report back to teams where issues arise.*
- *Reflection memos: individual one-page reflection tying a teamwork incident to module concepts (graded for insight, not positivity).*
- *Summative peer evaluation: Weighted component of final grade; rubric shared on day 1 (see Table 2.6.1 for an example).*

Table 2.6.1. Example of peer evaluation rubric

<i>Dimension</i>	<i>Meets expectations</i>	<i>Below</i>	<i>Exceeds</i>
<i>Contribution quality</i>	<i>Delivers tasks on time; work meets agreed standards; seeks feedback</i>	<i>Missed deadlines; superficial work</i>	<i>Proactively improves team output; mentors others</i>
<i>Communication</i>	<i>Shares info promptly; listens; responds respectfully</i>	<i>Silent or dominating; slow replies</i>	<i>Facilitates dialogue; models active listening</i>
<i>Accountability</i>	<i>Owens mistakes; follows through on commitments</i>	<i>Blames others; evasive</i>	<i>Holds self and others to high standard constructively</i>
<i>Collaboration</i>	<i>Participates in meetings; supports team decisions</i>	<i>Minimal engagement; undermines decisions</i>	<i>Builds cohesion; mediates conflicts effectively</i>

9. Closing script (5 minutes)

Close by reinforcing what the students just accomplished: they surfaced the behaviours that help teams succeed (and the habits that derail them), tested their collaboration under time pressure, and translated those lessons into concrete norms

in their team charter. Emphasise that a charter is a living agreement — not a one-and-done document — so they should revisit it at key moments (midpoint check-ins, in case of conflict, before major deadlines) and adjust as needed. The punchline: strong outcomes don't happen by accident; great products come from great processes, and their performance will reflect both.

4.5 Resources and further reading

In addition to the literature referenced in this chapter, we also suggest Aggrawal et al. (2024) and Jehn and Mannix (2000) on Teamwork conflict management and conflict resolution, Aguado et al. (2014) on the Teamwork Competency Test, Aubé et al. (2011) on skill acquisition and retention in individuals and teams, and Kozlowski et al. (2001, 2018), Mathieu et al. (2008), Oakley et al. (2004) and Ohland et al. (2012) on the effectiveness of teams. We also recommend Loughry and Tosi (2008) on performance monitoring, Rapp et al. (2021) on emergent states in teamwork and Reeves et al. (2018) and van der Vegt et al. (2001) on teamwork in professional practice.

5 Conclusion

Teamwork should be treated as a teachable engineering competency rather than an assumed byproduct of group work. Effective teamwork develops when educators intentionally design for it through explicit instruction, thoughtful team formation, structured opportunities for feedback and reflection, and timely support for conflict management and accountability. By focusing not only on task completion but also on team processes and emergent states over time, engineering programmes can better prepare students to collaborate effectively in diverse, complex, and interdisciplinary professional settings.

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AI statement

During the preparation of this work, the authors used ChatGPT to verify grammar. After using this tool, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

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2.7

Oral Presentation

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Oral presentation is an important professional communication skill for engineering students, both in educational settings and in future engineering practice. This chapter approaches oral presentations as rhetorical, situational communicative events. It first defines the skill and its main characteristics by drawing on classical and modern rhetoric. It then explains why oral presentation matters in engineering education, particularly as a learning and assessment activity. The final sections translate these insights into educational design principles, discussing how presentation skills can be taught, practised, assessed, and scaffolded across an engineering curriculum.

1 Definition: what is oral presentation?

1.1 Classical and modern rhetoric as the foundation of oral presentation

Oral presentation is historically rooted in the tradition of classical rhetoric, a discipline that emerged in ancient Greece and Rome to describe the art of speaking persuasively in public. When discussing oral presentation from a rhetorical point of view, we use classical rhetorical terminology as an analytical and practical framework. These terms allow for a level of analytical precision that is suited to describing the conceptual complexity of rhetorical practice. An influential starting point for this framework is provided by the work of the ancient Roman author Quintilian.

Quintilian (c. 35 - c. 100 AD), in his *Institutio Oratoria* (trans. Russell, 2002), outlines a complete rhetorical approach consisting of five stages: invention (*inventio*), arrangement (*dispositio*), style (*elocutio*), memorisation (*memoria*) and delivery (*actio*) (Kennedy, 1994). This structure formed the core of what would become the Western tradition of public speaking.

In classical rhetorical education, learning public speaking was conceived as a structured progression through four stages of increasing complexity (Kennedy, 1994). The first step, *grammatica*, focused on learning and mastering the language, which formed the linguistic foundation for rhetorical training. This was followed by the *progymnasmata*, a series of written and stylistic exercises — such as fables, comparisons, and maxims — designed to build basic rhetorical skills. Next came the *declamatio*, in which students practised oral delivery in simulated situations, often involving persuasive or judicial speech scenarios. Finally, the most advanced stage was the *practica oratoria*, where learners engaged in the actual professional practice of rhetoric, such as public debate, legal pleading, or ceremonial speech. From this perspective, we position the teaching of oral presentation to engineering students in controlled educational settings as a modern equivalent of the classical *declamatio* stage.

Modern interpretations of classical rhetoric often emphasise the three means of persuasion defined by Aristotle in his *Rhetoric*: *logos* (appeal to reason), *ethos* (credibility of the speaker), and *pathos* (emotional appeal). These remain present in academic and professional oral presentation situations (Braet, 2007), where speakers often not just aim to inform but also to persuade. We consider the Aristotelian means of persuasion to be a helpful tool for speakers to analyse communication situations: to what extent does the situation require an emphasis on argumentation, what is the relationship between speaker and audience, and what emotions and values are involved that need to be addressed?

These classical roots accentuate our idea that presentations are rhetorical, situational communicative events. Drawing on Bitzer's (1968) notion of the rhetorical situation, we understand a presentation as a response to a specific exigence, audience, and set of constraints. There is a demand for communication to bring about an effect or change (exigence), an audience to respond to such a message, and constraints, including beliefs and attitudes, but also location (type of event, shared space, or

mediated event), and time of day. An effective presentation is therefore not merely clear or confidently delivered in general, but functions as a fitting response to its communicative situation. This situational awareness provides a solid basis for presentation education, preparing students to communicate across different settings, genres, and disciplines (Threadgill & Paulson, 2018).

1.2 Oral presentations in educational contexts

In educational settings, an oral presentation is commonly defined as a structured, pre-prepared verbal delivery of content to an audience, often accompanied by visual aids (PowerPoint-slides) and followed by a Q&A session (van Ginkel et al., 2015). In the context of this handbook, we use the glossary definition: presentation skills are the ability to give a clear, organised and logical speech and answer questions adequately and with elaboration (Leandro Cruz & Saunders-Smiths, 2019).

Oral presentations in higher education typically serve as both a learning activity and an assessment format. They require students to explain, argue, or reflect on content in their own words. Unlike everyday informal speaking, they are often evaluated based on clarity, structure, audience adaptation, and delivery (Carless & Boud, 2018). We consider strong oral presentations to reflect both information literacy skills and interpersonal communication skills, including adaptability, active listening, and audience awareness (Leandro Cruz & Saunders-Smiths, 2019). Didactically, oral presentations are valued because they engage students in self-directed learning and promote active knowledge construction (Garrison, 1997). Students must often make deliberate choices about content selection, audience adaptation, and rhetorical strategy. These processes foster autonomous motivation (Ryan & Deci, 2000) and strengthen self-regulation (Zimmerman, 2002). In contrast to written assignments, the speaker cannot hide behind text, but must perform understanding in real time, often in interaction with peers or experts. This performative aspect emphasises the presentation method itself: the way in which content is staged using voice, visuals, posture, and timing.

The didactical value of oral presentations has contributed to their increasing use as an assessment method since the emergence of generative AI tools in higher education (Stephenson et al., 2025). To tackle the challenges of academic integrity and knowledge processing raised by GenAI, oral assessment is considered to promote authenticity and critical thinking skills (Corbin et al., 2025). However, relying on oral assessments such as presentations comes with its own challenges: students' performance may be influenced by a possible anxiety for speaking in public (Stephenson et al., 2025), and it may lead to assessing different learning outcomes (Corbin et al., 2025). These considerations underline why we believe that effective instruction in oral presentation skills should not only prepare students for their professional careers but also support valid assessment of content knowledge and skills.

2 The relevance of presentation skills for engineers

In interdisciplinary work environments, engineers often engage in persuasive communication to make decisions with various stakeholders, which requires awareness of the shared situation, emotional engagement, and credibility of those involved (Coso Strong et al., 2021). Although engineering presentations that were evaluated as successful included rhetorical techniques and audience adaptation strategies (Dannels, 2009), introductions of speeches about engineering in practice contain few techniques to draw attention or establish rapport with the audience (Van de Mierop et al., 2008). We believe that awareness of such rhetorical aspects should be woven into engineering curricula, for example by introducing students to Aristotle's means of persuasion (Rakedzon & Hazzan, 2025) — both in explicit oral presentation training and by applying oral presentations as teaching and assessment methods throughout the curriculum.

Universities increasingly recognise the value of structured presentation training and education by giving it a more central role in STEM programmes (De Grez et al., 2012; Van Ginkel et al., 2017). Structured presentation training can enhance students' communication competence and strengthen their confidence (van Ginkel et al., 2017). Moreover, De Grez et al. (2012) show that such training improves students' ability to tailor content to the audience and context. This way, higher education brings together rhetorical training and personal development to prepare for professional practice.

3 Forms of implementation

What are effective ways to integrate oral presentation skills in engineering education? To answer this question, we first explain approaches to include oral presentation skills on a curriculum level (3.1), touching on the progression of students throughout a study programme and scaffolding practices. Next, we describe approaches to design a presentation skills module (3.2), followed by an overview of challenges and opportunities for developing presentation skills (3.3).

3.1 Integrating oral presentation skills into engineering curricula

As engineering students need to be prepared for various presentation situations and genres, we argue that it is important for students to progressively develop and practise the skill throughout an engineering curriculum. This means using scaffolded instruction within a curriculum in which presentation learning outcomes become increasingly demanding. This section first distinguishes between fundamental and more advanced presentation skills, before discussing approaches and practices to integrate such skills into a curriculum.

From fundamental to advanced presentation skills

At an undergraduate (bachelor) level, we recommend that engineering students first acquire the fundamentals of effective presentations. This involves practising delivery skills to ensure that audiences are able to process information: adopting an appropriate posture (Steehouder et al., 2012), using natural gestures (Andeweg & Baars, 2019), establishing eye contact (van der Laaken & van der Laaken, 2013), and

applying clear and attractive voice use (Steehouder et al., 2012). In addition, bachelor students benefit from learning to structure their presentation according to the introduction-body-conclusion format: a concise introduction to state the presentation aim and main points, a logically ordered body, and a conclusion that recaps the key message and signals closure. Furthermore, students should practise designing clear, supporting, and non-distracting visuals (slides), for which Mayer's multimedia learning theory (1989) offers useful guidelines. Finally, students should be trained to handle Q&A sessions by listening attentively to questions and responding in a structured and concise manner.

At the advanced stages of their studies (end of bachelor level or master level), students are expected to further refine their professional presentation skills to negotiate the nuances of more complex presentation situations and apply rhetorical techniques (Dannels, 2009). Challenges at the advanced level include presenting to a mixed audience (Coffelt et al., 2024), for example simultaneously addressing peers, laypersons, managers, and legal professionals, and presenting across different genres. Research indicates that a one-size-fits-all approach is insufficient in such cases (Jariwala et al., 2024). For instance, (professional) speakers vary their use of ethos, pathos, and logos, vocabulary, and rhetorical techniques when they address similar topics in different settings, such as TED talks in contrast to conference presentations (Scotto di Carlo, 2014; Wackers, 2021). More advanced situations also involve managing a demanding Q&A session, such as moderating a panel discussion.

A particular advanced presenting skill for engineering students is to incorporate a technical demonstration into their presentation, as it combines logistical and communicative skills. Although empirical evidence on the effectiveness of technical demonstrations in engineering presentations is limited, related research suggests that demonstrations can enhance audience engagement (Bobbe et al., 2023) and are most effective in combination with audience interaction (Sharma et al., 2010). From a rhetorical perspective, a demonstration can strengthen logos (by making a theoretical claim observable), pathos (by doing something that is likely to spark attention and curiosity) and ethos (by demonstrating skill and competence in performing the technical demonstration).

Example 1. How can you coach students in giving an effective demonstration?

We recommend introducing students to the following steps, which can be used both as guidelines for preparing a demonstration and focus points for teacher and peer feedback:

- 1. Conducting a safety and feasibility check before the presentation, meaning that presenters should verify whether the demonstration can be safely performed under the available conditions (e.g., checking whether the audience is at a proper distance for demonstrating a prototype, or verifying whether protective clothing is required for audience members who volunteer to assist);*
- 2. Stating the purpose of the demonstration and how it relates to the central claim of the presentation (logos);*

3. *Inviting the audience to formulate a prediction or hypothesis;*
4. *Performing the demonstration with clear visibility and, if required, guiding explanation;*
5. *Inviting the audience to discuss their interpretation of the demonstration ("what did you observe?", "how does that compare to your expectations?");*
6. *Explicitly synthesising the outcome with the theoretical or technical argument developed in the presentation.*

From integration into a content-based module to a learning trajectory

To develop students' oral communication skills, oral presentation is often included as part of a content-based module or project. Embedding communication tasks within content-rich contexts can strengthen students' communicative competencies, particularly when such tasks are meaningfully aligned with disciplinary learning goals (Cochrane, 2009; De Grez et al., 2009). Carlsson et al. (2010) emphasise the importance of clearly defined roles for both subject-matter experts and communication experts: effective collaboration between these parties facilitates presentation assignments with well-articulated learning outcomes that go beyond the abstract instruction to *'give a good presentation'*.

Example 2. Oral presentations at Delft University of Technology

At Delft University of Technology most faculties offer an integrated module in oral presentation as part of the undergraduate curriculum. Typically, this module is compulsory and embedded within a project-based setting, requiring students to present about the content of their project. Ideally, learning goals and presentation assignments are not only adapted to module content, but also to the students' level: first-year undergraduate students prepare presentations to peers and instructors, whereas master students and PhD students are often challenged to gear their talks to various audiences.

Rather than providing a one-off module, we believe that a more durable approach is to scaffold oral presentation skills across the curriculum via a learning trajectory. Such an approach allows students to repeatedly practise and extend their speaking skills from the first year through graduation. Apart from integrated presentation skills modules, you are recommended to include other interventions across the curriculum to help develop presentation skills, such as presentation assignments with feedback moments and follow-up consultations by (skills) lecturers — moving from intensive teacher guidance to student-led, question-driven consults.

To develop an effective learning trajectory, you should keep in mind several design principles. First, using similar evaluation criteria for presentations across different modules provides continuity and clarifies expectations. Second, develop or use materials about presentation skills, such as feedback forms, instructional videos, or assessment rubrics. Make these available to both students and teaching staff, to reinforce shared standards. Third, use a consistent feedback vocabulary (e.g.,

audience awareness, structure, delivery) to foster shared understanding and help students track their own progress more effectively. Example 3 shows how a presentation skills learning trajectory is included at Delft University of Technology. Table 2.7.1 shows example criteria and competence levels from two different categories in the presentation skills rubric that can be used (and extended) throughout a learning line.

Table 2.7.1: TU Delft Centre for Languages and Academic Skills rubric for presentation, showing two examples of criteria to evaluate fundamental and advanced presentation skills. The first row represents the fundamental delivery criterion 'volume and tempo'; the second row represents the more advanced criterion 'language and interaction' from the category 'audience adaptation'. Descriptions of observed speaker behaviour are distributed over four competence levels: 'poor', 'mediocre', 'sufficient' and 'good'. Note that the overall rubric contains more categories and criteria, and that the evaluator's interpretation of speaker behaviour depends on the presentation situation (e.g., module type and assignment).

<i>Criterion (evaluation category)</i>	<i>Poor</i>	<i>Mediocre</i>	<i>Sufficient</i>	<i>Good</i>
<i>Volume and tempo (delivery: fundamental)</i>	Speaker speaks too loudly, too quietly, too slowly or too quickly	Speaker sometimes speaks too loudly, too quietly, too slowly, or too quickly	Speaker uses effective volume and tempo	+ Speaker uses pauses effectively to maintain the audience's attention
<i>Language and interaction (audience adaptation: advanced)</i>	Audience is never addressed directly (if relevant) Or: language is unprofessional	Audience is only addressed sporadically (if relevant) Or: language can be unprofessional at times	Audience is addressed frequently and effectively (if relevant) And: language is usually correct and professional	+ Speakers engage the audience in the presentation effectively + Speakers connect with audience's perceptions and experiences

Example 3. Integration of presentation skills as a learning trajectory

In the curriculum for Applied Physics at TU Delft, first-year undergraduate students get acquainted with fundamental presentation skills. In a design project, they follow a self-guided online instruction on presentation elements such as delivery and basic presentation structure and record a video of their presentation. A skills lecturer gives feedback on this video, after which students process this feedback and prepare a live presentation to their peers and project instructor, who then provide (peer) feedback. Feedback is limited to fundamental presentation skills, such as delivery. Table 2.7.1 provides an excerpt of the rubric that skills lecturers, peers, and project instructors use to give formative feedback. The upper row shows an example of one delivery criterion (volume and tempo).

In the second year of the bachelor curriculum, a more intensive presentation skills module is integrated into an interdisciplinary project in which Applied Physics students collaborate with Business Management students. Building on their first-year fundamental presentation skills, students are guided in preparing presentations for mixed audiences of stakeholders and peers. Students are invited to reflect on their progress compared to the first-year presentation. Rubrics introduced in the first year are extended with categories such as audience adaptation. The second row in Table 2.7.1 provides an example of an evaluation criterion for more advanced presentation assignments to mixed audiences. Furthermore, second-year students manage a more challenging Q&A session in which they can expect questions from various stakeholder perspectives and need to respond to opposing or conflicting ideas.

3.2 Module design principles and teaching methods

The design of a dedicated oral presentation module depends on factors such as the module's position in the curriculum, students' prior knowledge, and potential connections with other subjects. While these contextual elements shape the implementation, we believe that several didactical *building blocks* are consistently present in oral presentation modules: 1) defining learning outcomes; 2) engaging with rhetorical and presentation theory; 3) practising through authentic tasks and targeted exercises; 4) providing and receiving feedback; and 5) engaging in structured reflection.

Formulating learning outcomes

When you formulate learning objectives for an oral presentation module, we recommend aligning them with the module's position in the curriculum and with students' developing expertise. Less experienced students usually need more explicit scaffolding to construct a fitting response to the rhetorical situation. You can offer this support across the classical rhetorical canons: helping students select relevant content (*inventio*), organise it coherently (*dispositio*), formulate it appropriately and design supporting visuals (*elocutio*), rehearse and prepare for delivery (*memoria*), and perform the presentation effectively (*actio*). More advanced students, by contrast,

should gradually take greater responsibility for making these choices themselves. We do not see this as a strict distinction between basic and advanced skills, but as a continuum of increasing expertise.

Cognitive load theory can help you decide how much scaffolding students need at a particular stage in that continuum (Sweller et al., 2019). Support should be sufficient to make the presentation task manageable but should gradually be reduced as students become more capable of analysing the situation and adapting their presentation choices independently. This scaffolded approach differs from a purely incremental sequence in which students practise one isolated competence after another. Instead, intermediate tasks function as guided approximations of increasingly complex presentation situations. Research suggests that such scaffolding can enhance contextual transferability: students become better able to adapt what they have learned to different audiences, genres and rhetorical situations (van Ginkel et al., 2015).

Practising with the theory: flipping the classroom

We recommend using class time primarily for practice, feedback, and guided application. The flipped classroom is a widely adopted didactic strategy to do this (Irianti et al., 2024). Following this approach, students read and watch (often digital) materials prior to class and apply the prepared theory in class via practical assignments and exercises. This increases time-on-task, helps students connect theory with delivery, and allows you to provide individualized, scaffolded support during practice (Bishop & Verleger, 2013; Chen et al., 2014; van Alten et al., 2019).

For oral presentation skills, flipping the classroom is particularly suitable because presentations are inherently performative: knowledge of rhetorical theory alone is insufficient unless enacted. By engaging with theory before class, students arrive prepared to apply concepts immediately in authentic practice situations. Moreover, evidence suggests that flipped presentation modules foster higher student engagement and self-efficacy, as learners take greater responsibility for their preparation and performance (Thai et al., 2017).

Research on skills education in higher education highlights the importance of authentic learning tasks: tasks that closely resemble the communicative situations students will encounter in professional contexts (Gulikens et al., 2006). In oral presentation modules, this implies designing assignments that go beyond “classroom performances” and instead simulate realistic settings such as a pitch for a client, a conference presentation, or a team briefing. Authentic tasks have been shown to increase intrinsic motivation (Herrington et al., 2010) and improve transfer of learning, as students can more readily apply the competencies they develop in other contexts (Smith & Frymier, 2006).

Practising with presentation exercises

Beyond full presentations, you can include short, targeted in-class presentation exercises. These resemble the progymnasmata in classical rhetoric, which foster stepwise mastery of rhetorical tasks and provide a didactical blueprint. Early exercises

might include brief self-introductions, paraphrasing of existing texts, or describing visual material such as an object in class or taken from their own bag, which strengthen *inventio* and *elocutio*. As students advance, you can introduce exercises with increased rhetorical complexity, such as defending a position in a short debate (focusing on structure), delivering a prepared persuasive speech (delivery), or improvising responses to audience questions (integrating multiple tasks). Improvisation exercises can enhance spontaneity, adaptability, and communicative confidence; see Phelps et al. (2021) for examples of exercises.

Feedback on presentations

In our view, feedback remains a cornerstone of effective oral presentation instruction. Both instructor feedback and peer feedback serve distinct functions. While instructor feedback has been shown to be more effective in improving performance (van Ginkel et al., 2017), peer feedback provides metacognitive benefits for the giver, enhancing their own internalisation of assessment criteria.

Because oral presentations involve personal exposure, feedback is often perceived as more direct and personal than feedback on written work (Agricola et al., 2020). This heightened sensitivity can affect students' receptiveness: criticism of a performance may be interpreted as criticism of the person. To safeguard a psychologically safe learning climate, lecturers should employ constructive communication strategies sensitive of students' self-perception. Research on feedback in communication education confirms that the tone, specificity, and delivery of comments strongly influence whether feedback is experienced as constructive or threatening (Smith & King, 2004; Trees et al., 2009). Therefore, we recommend the step-by-step feedback approach explained in Example 4.

Example 4. How to guide the peer feedback process in a presentation class

- *Dedicate a specific moment in class to discuss effective feedback strategies.*
- *Introduce students to specific feedback criteria (as described in Table 2.7.1) in an early stage of the module to help them develop a more precise feedback vocabulary.*
- *Enable students to first practise giving feedback on a particular category or criterion before extending this to multiple evaluation aspects.*
- *Ask speakers to reflect on their own presentation first, as an initial response and opportunity to release possible tension they built up.*
- *Invite the audience to respond with their general impression before moving into the more detailed and specific feedback, so that the audience can attune their feedback to the speakers' initial reflection.*

Reflecting on presentations

Reflection consolidates learning by fostering critical awareness of strengths and areas for improvement (Sterling et al., 2016). Research indicates that students tend to overestimate their own presentation competencies, in comparison to the evaluations of instructors (De Grez et al., 2012). As a result, unguided self-assessment may

provide an inflated view of performance, which underscores the importance of structured reflection guided by theoretical frameworks or external feedback.

Although reflection is one of the building blocks for a module on oral presentations, its educational value diminishes when it is narrowly tied to the formal assessment criteria of the final performance. Studies on assessment practise caution that such a focus may encourage students to treat reflection primarily as a strategic exercise to maximise grades, rather than as an authentic process of self-examination and growth (Boud & Falchikov, 2007; Sadler, 2005). In this scenario, students engage in what Sadler describes as strategic compliance: they focus on aligning their reflections with the stated criteria to satisfy evaluators, rather than on developing a deeper understanding of what constitutes effective presentation. As a result, reflection risks becoming instrumental rather than developmental, which undermines its potential to foster genuine improvement. To avoid this, reflection activities should be framed as opportunities for developmental learning rather than as mechanisms for demonstrating compliance with assessment criteria. Models such as Kolb's Experiential Learning Cycle (1984) and Gibbs' Reflective Cycle (1988) can help achieve this by guiding students toward systematic, theory-informed self-analysis that extends beyond the immediate assessment task.

3.3 Challenges for developing oral presentation skills

In this section we discuss three challenges that integrating oral presentation skills into engineering brings about; the first two are related to classroom practice of teaching this skill, the third pertains to skills implementation on an institutional level.

Dealing with public speaking anxiety

Public speaking anxiety is a well-known barrier for students in presentation classes and public speaking assessments, and the increased stress levels involved can negatively influence students' experience of higher education in general (Grieve et al., 2021). Depending on the severity of public speaking anxiety, you can apply different remedial approaches. According to Bodie (2009), a combination of remedial techniques usually is most effective. Students who heavily suffer from public speaking anxiety are not likely to be helped by skills training alone and may require (psychological) treatment by a professional first. However, other students can benefit from classroom interventions and exercises at home.

In the classroom, you are encouraged to create conditions for a safe space and address the issue of public speaking anxiety. It may be helpful for students to acknowledge that they are not the only ones facing this challenge. As not all students feel comfortable speaking up about this topic, you can provide students with the opportunity to address the matter individually to you or in a small peer group. You can share exercises or develop a step-by-step plan with individual students; start with small, manageable tasks such as adopting an effective posture. In class, some other common approaches are: practising in small groups of students who are familiar with each other, giving (peer) feedback on specific actionable aspects of delivery or performance (such as gestures or eye contact), incremental progression (one

competence at a time), and explicitly acknowledging students' qualities. Beyond the classroom, you can encourage students to practise visualising their presentation as a successful event (Bodie, 2009). You can agree with the student to evaluate such interventions before and after each in-class presentation. Although time-consuming, it is critical and worthwhile to build a relationship of trust with students with public speaking anxiety.

Adapting to varying levels of experience in a presentation class

Another challenge in teaching presentation skills is adapting to different levels of experience and mastery of presenting skills within a cohort or class of students. This issue typically occurs in postgraduate degree programmes, which are open to students from a range of undergraduate programmes. Some students have had little experience with presenting in their former education (secondary school and undergraduate programme), whereas other students have followed study programmes that heavily emphasise presenting. Such a variation in presentation experience in a presentation class can affect student motivation; in particular, more experienced students can feel a lack of purpose and progression. Furthermore, variation in experience can impact student performance in presentations that are part of content or knowledge-based assessments in the curriculum, which requires consideration in a (project) module and curriculum assessment plan.

To tackle this, there are various ways you can differentiate within a module or class. A first approach is to compose groups based on experience and gear feedback, assignments, and exercises to the level of the class. Drawbacks of this approach are that it is time-consuming for teachers to determine the students' entry level, that students may find it challenging to self-assess their level of presentation skills, and that such a set-up would not allow students who need to start at a more basic level to learn from high-performing peers. A second way to tackle a possible lack of motivation is to design more complex formative presentation assignments for high-performing students. You can invite students to formulate their personal learning outcomes that exceed the module's basic learning outcomes, challenge them to include rhetorical strategies (compelling narratives or stylistic devices, for example), and invite them to fulfil the role of moderator in a group discussion. Finally, you can introduce presentation skills electives that aim for a more advanced level or specific presentation genres (e.g., popular scientific presentations, speeches, or TED talks), geared to experienced or high-performing students who wish to further develop their skills beyond the programme outcomes.

Allocating sufficient resources to presentation skills

Acquiring effective presentation skills requires practice, feedback, and self-reflection. In an engineering curriculum that is expected to contain content-based knowledge and a range of academic skills, allocating sufficient resources and credits to presentation skills it is often not prioritised. A combination of recommendations discussed in sections 3.1 and 3.2 could be resource-efficient when applied simultaneously: integrating presentation skills into content-based modules, ensuring

the application of similar presentation evaluation criteria and access to (online) materials and exercises throughout the curriculum, including presentation skills at the start of a new curriculum design, and scaffolding presentation skills so that students can progressively develop presentation competencies and skills. This way, institutions and study programmes avoid a one-module-fits-all approach and instead carefully consider students' progression in developing presentation skills.

4 Conclusion and recommendations

Oral presentation skills develop through deliberate, repeated practice. Give students multiple opportunities to present throughout the curriculum, rather than concentrating presentation training in a single assignment or module. These opportunities can take different forms: presentations embedded in disciplinary modules, a stand-alone module on oral presentation, or consultation sessions with communication experts. Whatever the format, make core presentation theory available to students and teaching staff, use comparable feedback criteria across modules, and develop a shared vocabulary for discussing presentation performance.

When assessing presentations, use a manageable set of criteria. Within an individual module, you should scaffold students' development. Across the curriculum, you should increase the complexity of presentation tasks. In introductory modules, address core components such as delivery, structure, visualisation, and Q&A. For more advanced modules, you might challenge your students to respond to a more demanding rhetorical situation, speak to mixed audiences, and manage more complex forms of presentation formats and more complex forms of interaction.

If you design a dedicated oral presentation module, include five building blocks. First, formulate learning objectives that match students' level and fit the programme's learning trajectory. Second, provide students with relevant theoretical foundations, preferably outside of class in a flipped-classroom format. Third, use contact time for practice: students should enact, test, and refine the theory through prepared assignments and shorter targeted exercises. Fourth, provide systematic feedback, combining instructor feedback with structured peer feedback. Fifth, guide students in reflecting critically on their performance and development, so that reflection supports future improvement rather than merely documenting what happened.

At programme level, safeguard the coherence of the presentation learning trajectory. Students usually present in several modules, often taught by different instructors. Designate coordinators who monitor whether assignments become progressively more challenging, whether assessment criteria remain broadly consistent, and whether instructors use compatible terminology. Make foundational presentation theory readily available to both staff and students, for example through a shared handbook or learning management system. In combination, curricular recurrence, coherent standards, accessible theory, practice, feedback, and reflection create the conditions for cumulative, scaffolded growth in oral presentation skills.

Finally, in addition to the literature referenced in this chapter, we also recommend *Classical rhetoric for the modern student* by Corbett and Connors (1999).

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2.8

Written Communication and Reporting

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To prepare engineers for the writing tasks employers expect them to perform in academia and industry, writing should be embedded in engineering education. In this chapter we show how engineering programmes should design education in written communication. Since the launch of generative AI may impact education in writing, we also discuss how to deal with the influence of generative AI in engineering writing education. After defining written communication in engineering and discussing theories of writing and writing education, we present three evidence-based principles for the design of education in written communication: embedding writing in the discipline, using realistic, authentic genres, and applying active learning. In addition, we recommend that teachers in communicative skills collaborate with engineering teachers to develop writing education. Finally, we suggest the use of rubrics and mitigated criticism for practical and effective assessment of writing. We provide examples of study programmes that have applied these principles.

1 Definition

1.1 Writing in engineering

Engineers spend 15 to 30% of their work hours on writing (Passow & Passow, 2017). Engineering alumni have rated communication skills to be highly important in their professional career — more so than was emphasised than during their engineering degree (Lattuca et al., 2014). Industry representatives expect a high level of writing skills from engineering graduates (Leandro Cruz & Saunders-Smiths, 2019). Clearly, writing skills are indispensable for graduating engineers.

Leandro Cruz & Saunders-Smiths (2019, p. 13) define writing skills in engineering fields as the ability to develop “*a logical, accurate, detailed, and organised report/paper without grammar mistakes and with accurate references*”. This definition highlights six key components:

- *Logical* refers to the arguments presented. They should be clear and logically sound. Using incorrect phrasing or fallacious arguments reduces the credibility of the author and impedes a good understanding of the text.
- *Accurate* refers to the quality of information presented in a text. Accuracy goes beyond the use of factually correct information. In engineering writing, a clear, unambiguous choice of words is expected.
- *Detailed* refers to the amount, quality, and depth of content a text should cover. Texts should contain sufficient detail to cover necessary content, yet not so much detail as to distract from the main point.
- *Organised* refers to the order and grouping of information within a document. The format of technical documents should align with the readers’ expectations and aid the presentation and processing of information.
- *Without mistakes* refers to the ability to write without language errors. Although the provided definition refers to grammar mistakes, this guideline also applies to errors in spelling and punctuation. Mistakes can cause confusion among readers.
- *With accurate references* refers to the need to incorporate and discuss sources in text. Writing is often based on work by others and should show credit where credit is due, thus supporting the strength of the claims in a text. In addition, referencing should follow specific formats that are common in engineering practice.

This definition focuses on reports and papers as writing genres. In this chapter, we focus on teaching these genres, as students will have to write these during their degree and in the engineering workplace. Though engineers should also be able to write memos, emails, safety instructions etcetera, these genres are either taught in secondary education or on the job. However, many strategies discussed in this chapter are applicable to teaching a wide range of genres.

1.2 Theories of writing

Several theories point towards the methods through which people write. These theories inform the way writing education is defined and designed.

First, writing is not a linear process. Flower and Hayes (1981) define a cognitive process theory on writing. Broadly, the writing process contains three phases: planning, writing, and revising. In practice, writers apply these phases in recurring fashion: they may revise sections before completing the text or return to the planning phase while writing. In addition, writing is a goal-oriented process, in which writers develop an understanding of a topic through writing and therefore adjust their goal throughout the writing process. Writing, therefore, is not just a way to communicate ideas, but also to develop ideas.

Second, writing is a socially situated activity, in which authors adapt their writing to their audiences and fulfil expectations readers have about genres: shared conventions in style, content, and form in texts with similar purposes. Genres are "*choices which represent effective ways of getting things done in familiar contexts*" (Hyland, 2003, p. 22). Writing conventions differ between settings and fields of study, for example:

- A design report will contain a high level of detail, technical language, and organization in chapters and sections. Conversely, an email is brief, contains natural language, and is organised in a more rudimentary form.
- In most science and engineering fields, it is unusual for writers to use personal pronouns in research papers, though this is becoming more common. Writers in mathematics, however, commonly use the personal pronoun 'I' in papers in which they present their proofs.
- Students of Life Sciences and Molecular Sciences will regularly write up their research results in lab reports, whereas architecture students will rarely have to write such a report.

More recently, the emergence of generative AI (GenAI) tools and Large Language Models (LLMs) such as ChatGPT, Claude, or Gemini has offered new methods to produce written text. Users supply these tools with a prompt, through which the tool generates an output. As such, LLMs can produce a large variety of texts faster than any human writer could and can support writers in planning and revising texts. There is no consensus yet on the use of LLMs in the writing process: their use is a controversial topic, and current research provides mixed perspectives on their efficacy. Section 2.2 discusses the current discourse around LLMs in writing education.

1.3 Writing and linked competences

Overall, there are indications that academic writing abilities correlate with higher academic achievement (Kuiken & Vedder, 2021). Although the direction of this relationship is uncertain — whether good students become good writers, or vice versa — writing is unmistakably a competency that is linked to many other skills. Kruse (2013) identifies six domains to which writing competency is connected, which require a separate set of sub-skills:

- *Disciplinary knowledge.* Students cannot perform academic writing without a proper knowledge foundation. Similarly, students build knowledge through writing.

- *Process and procedural skills.* Writing is a process containing a diverse set of components, such as planning, research, idea generation, and revision. Students can only learn and apply these steps through practice.
- *Communication and discourse knowledge.* Students should be able to relate the contents of a text to its audience and the relevant discursive community.
- *Media use.* Writers use various media to produce and share text, that students should be aware of and should be able to use. In the past decades, text production has shifted from physical to digital means, and this shift is currently proceeding with the introduction of GenAI.
- *Genre knowledge.* Students should be aware how the various characteristics of texts relate to the functions of a text and the expectations of an audience.
- *Linguistic skills.* Students need language skills to write properly, both lower-order skills (spelling and grammar) and higher-order rhetorical skills.

1.4 Entry and exit levels for writing education

Study programmes can expect students who enter higher education to have sufficient competencies in the basics of writing: lettering, spelling, grammar, and basic composition skills such as dividing a text into sections and paragraphs. However, this is not always the case in practice; in such cases, remedial programmes for first-year students and writing centres can alleviate this issue to a certain extent (Kuiken & Vedder, 2021).

One notable difference in students entering engineering programmes is the difference between first- and second-language writers (L1 and L2 writers, respectively). The Common European Framework of Reference for Languages (CEFR) identifies different levels for language skills (Council of Europe, n.d.-a) and levels for written communication (Council of Europe, n.d.-b). Many universities in Europe ask of students that they have a near-native language entry level in their own language (C1 in terms of the CEFR) and end of secondary education level (B2 in terms of the CEFR) of English for English-language study programmes, if students do not have English as their first language.

University engineering programmes in Europe are regularly taught in English, especially master programmes. Even when studying in their own country, students often write in a non-native language. Although many sub-skills of writing carry over between L1 and L2 writing (Gonca, 2016), students writing in a second language may have more difficulty, especially in aspects related to language use. For example, in a first-year writing module, Eckstein and Ferris (2018) found that L2 students made more language errors, used a less varied vocabulary, and were less confident in their language skills compared to L1 students.

In terms of exit levels, the overarching *Framework for Qualifications of the European Higher Education Area* defines learning goals for communication skills for bachelor, master and PhD programmes in European higher education (Table 1.1). To receive accreditation, engineering programmes must integrate these learning goals into their curricula.

Table 2.8.1: Learning goals for writing education (Bologna Working Group, 2005, Appendix 8)

<i>Level</i>	<i>Learning goal</i>
Bachelor	Students can communicate information, ideas, problems, and solutions to both specialist and non-specialist audiences.
Master	Students can communicate their conclusions, and the knowledge and rationale underpinning these, to specialist and non-specialist audiences clearly and unambiguously.
PhD	Students can communicate with their peers, the larger scholarly community, and with society in general about their areas of expertise.

These learning goals complement the definition of writing as provided by Leandro Cruz & Saunders-Smiths (2019): students should be able to communicate information, ideas, problems, solutions, conclusions, and rationale in subjects related to their areas of expertise to specialists, non-specialists, peers, the larger scholarly community, and society at large.

2 Why teach written communication and reporting?

2.1 Writing in the engineering workplace

In workplace situations, engineering graduates will regularly provide written results of their work. As stated in section 1.1, engineers spend a substantial amount of time on written communication. Although there are differences between the genres engineers use, they frequently share an overarching goal: to explain complex information in a clear manner. Students entering the workforce feel better prepared if they are familiar with the genres used in their future professional career (Ford et al., 2021).

Nevertheless, employers indicate a gap between the expected and actual level of writing from engineering graduates. Kirkpatrick et al. (2012) found that 52% of industry representatives considered mechanical engineering graduates to have weak communication skills, versus 9% who considered them strong. By contrast, 20% of educators considered their graduates to have weak communication skills and 40% strong. Although this survey targeted American universities and engineers, it is conceivable that such a gap is also present elsewhere.

Two reasons are given for this poor preparation. First, many engineering programmes incorporate writing skills through a general writing module. As a result, students may become familiar with transferrable writing principles, such as paragraph use and spelling, and generic genres, such as emails. However, university writing assignments do not always reflect writing situations that practicing engineers encounter. Even educators may not be familiar with engineering genres, if they have a non-engineering background or have only worked in academia. As a result, graduating students are unfamiliar with the genres they must be proficient in. In addition, engineering graduates cannot always determine which writing skills taught in an educational setting are applicable in a professional setting (Donnell et al., 2011).

Second, student and workplace writing have different goals. According to Paretto (2006, p. 189), student writing “*perform[s] knowledge so that teachers can evaluate concept mastery*”. Workplace writing, instead, “*communicate[s] information so that audiences can take subsequent actions*”. This requires authors to adapt their texts to the needs and understanding of their target audience. Even when writing assignments simulate real-life situations, the need to perform knowledge overshadows the need for audience adaptation.

This gap manifests itself in the quality of texts written. Conrad (2017) compared texts written by civil engineering practitioners and students. She found that practitioners value texts written in an unambiguous, predictable, and detailed way, with few grammar errors. This would make texts easy to read quickly and avoid liability concerns. By contrast, student texts were ineffective: they contained frequent grammar errors, unnecessarily complicated sentences, imprecise or inaccurate word choices, and a non-linear, incomplete organisation. According to Conrad (2017, p. 209), “*students sometimes knew they lacked knowledge ... [but] many also had profound misconceptions about what made writing effective*”.

Writing education, therefore, should aim to prepare students for any writing-related tasks they may encounter in the workplace. Section 3 discusses strategies to align student and workplace writing.

2.2 Influence of LLMs as a tool for writing

After the release of ChatGPT in November 2022, followed by other generative AI tools, discussion has emerged on the use of LLMs in writing assignments in higher education. LLMs can quickly provide convincing-looking texts, and students regularly resort to using these tools to help write their assignments. One might consider education in writing skills to become redundant, as students and engineers could outsource their writing to LLMs. However, AI-generated text cannot substitute human-written text. Concerns with LLMs in education fall into two categories: performance issues and learning issues. This criticism follows in part from studies or experiences in non-engineering fields but applies equally to engineering writing.

When it comes to LLM performance, there is ample criticism on the quality of AI-generated text. It often contains factually incorrect claims, non-existent references, fallacious argumentation, and an amplification of existing biases (Bender et al., 2021). In addition, LLMs can produce text in a vague and non-specific writing style that is unsuitable for most engineering-related genres (Kim et al., 2024). Without understanding the characteristics of appropriate writing, students may not notice these shortcomings and may fail to verify the accuracy of the provided claims and arguments, even if newer LLM versions may alleviate some of these issues.

While LLMs are a poor replacement for human writing, they can improve writing when used responsibly for specific writing tasks (Deng et al., 2025). Many educators fear that students outsource entire assignments to LLMs. However, students may also write assignments themselves and use LLMs only for part of the writing process. For example, they can use LLMs in the planning stage, by aiding with research or

brainstorming, and the revision stage, by improving the style of their written work or removing language mistakes. This way, weaker students could receive writing support without being dependent on staff or other students.

However, instructors need to properly support students when they are permitted to use LLMs. For example, proper prompt engineering is a prerequisite for desirable results. Students using LLMs produce higher-quality texts when using specific prompts, iterating their prompts, and critically evaluating the given output (Kim et al., 2025; Nguyen et al., 2024). Students who learn about the downsides of LLMs also adopt a more critical stance and reduce their LLM use, while still recognizing potential benefits (van Niekerk et al., 2025; see example 1).

It should be noted that studies about LLMs are subject to criticism (Bauer et al., 2025). These studies test writing in a controlled environment, such as writing a short essay, which is not reflective of the process of writing in an engineering classroom or company. Many studies are also methodologically flawed: there is no control group, or differences between AI-supported and non-AI-supported performance could be ascribed to other factors than AI use. Finally, and importantly, these studies only measure improvements in writing performance, not extended learning benefits.

This points towards a second, more fundamental criticism of LLMs: they potentially undermine student learning. University writing assignments often assess both writing skills and content learning. Writers develop ideas and critically reflect on their content while writing. These advantages are lost when they outsource writing to LLMs. Unlike performance issues, which newer versions of LLMs may alleviate, learning issues are an inherent part of using LLMs in writing education.

Research indicates that overreliance on LLMs leads to a reduction in skill development, creativity, critical thinking, and perceived ownership of texts. Fan et al. (2025) observed that students who used LLMs in the writing process produced higher-quality essays than students who did not. However, they did not achieve a better understanding of the content. In another study (Kosmyna et al., 2025), participants using LLMs to write essays used less cognitive load, had difficulty to quote a sentence from their work, and reported a lower perceived ownership of their work than participants using no additional tools or only search engines. These effects increased as they produced more essays. Therefore, if students consistently use LLMs to complete writing assignments, this indicates they may not have achieved the intended learning objectives.

As an early response to ChatGPT, educators sought to ban the use of LLMs in an educational setting, likening its use to plagiarism. However, such a measure is neither feasible nor productive. Students can easily circumvent AI bans and detection tools offer untrustworthy results (Corbin et al., 2025). There is a growing consensus that students would benefit from a more balanced view on LLMs as a writing tool. If students will have access to LLMs anyway, instructors should educate them on responsible AI use, for example by showing students how to use LLMs in a correct way when writing (see Example 1).

Furthermore, learning about LLMs prepares students for their future careers. European companies increasingly use LLMs and other forms of generative AI (Eurostat, 2025) to increase productivity. For example, they may incentivize employees to automate repetitive tasks, to write emails or to write or revise reports using LLMs.

Most universities are introducing guidelines for the use of LLMs in assignments. There are no definitive answers on how higher education institutions should revise their education. However, Corbin et al. (2025) provide a useful framework by dividing measures into discursive and structural changes. Discursive changes rely solely on communicating rules on LLMs, such as banning their use for certain tasks or requiring students to declare LLM use. Structural changes constrain the format of assignments to limit inappropriate LLM use, such as changing to supervised writing tasks or combining written assignments with oral discussions. Corbin et al. (2025) argue in favour of structural over discursive changes. Discursive changes are easy to implement, but they can be ambiguous for students and are difficult to enforce. Structural changes are difficult to implement but improve assessment validity in the long term.

Example 1. Teaching the pitfalls of LLMs in a writing module

To inform students of the pitfalls of LLMs, van Niekerk et al. (2025) performed an intervention study at Noroff University College, Norway, through a series of two tutorials in an academic writing module. In the first tutorial, students from several computer science engineering-related degrees received an overview of ChatGPT, outlining how it could be used. They generated an essay and then filled in a survey on their intention to use the application for writing, based on seven writing-related characteristics they observed in the essay generated. In a second tutorial, staff presented the flaws and limitations of ChatGPT and asked students to evaluate their essays based on these characteristics. Finally, students reflected on the use of ChatGPT and filled in a post-intervention survey.

Students adopted a more critical stance after the second tutorial. They saw ChatGPT as less useful than before and reduced their intention to use it, especially with regard to providing accurate references and offering critical insight into a topic. However, students still maintained their intention to use the application for structuring text or rewriting text in a more formal tone, areas where it presented fewer problematic results.

The authors present several limitations. First, the intervention took place when ChatGPT was relatively new, and students had limited prior exposure. Students may currently have more experience with LLMs and may be more aware of their limitations when entering university. Newer versions of ChatGPT and other LLMs could have improved functionality. These factors could reduce the efficacy of such an intervention in the future and could require educators to regularly revise the assignment. Second, the study provides only a single snapshot of one intervention, without conclusive evidence that students will retain this learning throughout their study programme. Especially under short deadlines or poor time management,

"students may still be tempted to use ChatGPT to provide material for an assessment" (Van Niekerk et al., 2025, p. 9).

It should also be noted that such an intervention only demonstrates the issues in AI-generated text. It does little to highlight the cognitive benefits of writing on your own, such as an increase in skill development, critical thinking, and perceived ownership.

3 Forms of implementation

3.1 Evidence-based principles of writing education

Study programmes should develop their writing education by defining clear learning outcomes, designing learning activities that support this learning, choosing or developing learning materials that support students in their learning in the correct way and at the correct time, and designing assessment methods that reliably evaluate whether the learning outcomes have been achieved. The principles behind the design of education in complex skills, such as writing, are well-known and validated through research (Biggs et al., 2022; van Merriënboer et al., 2025). For engineering writing education, we summarize three main principles. Examples 2 and 3 explain how educational programmes incorporate these principles in practice.

First, writing education in engineering should be embedded within the discipline (Russell, 2007). Embeddedness means that writing in engineering should ideally concern subjects that students are already involved in. This helps students to become acculturated within their discipline. They should learn to write as engineers, more specifically as a mechanical engineer, civil engineer, architect et cetera. This means they should learn about the specific ways that these engineers express themselves, which they often learn best from their own lecturers in the discipline. Example 2 shows how this embeddedness was implemented in a second-year scientific writing module in Aerospace Engineering at Delft University of Technology.

Second, writing education in engineering should make use of realistic, authentic genres (Hyland, 2003). In engineering, specific kinds of texts are used, such as design reports. Moreover, students should become familiar with academic genres such as the bachelor and master thesis and research articles. This enables them to practice academic ways of critical reading, thinking, argumentation, and use of and proper citation of sources — skills they will later need in the workplace. Writing modules that do not incorporate these genres may not teach topics that are relevant to engineers or may even contradict writing conventions among engineers (Wolfe, 2009).

Third, writing education in engineering should make use of active learning (Biggs et al., 2022; van Merriënboer et al., 2025). Active learning is an important design principle: students cannot learn to write by listening to lectures or reading background materials on writing alone. They should practice the writing process to increase their proficiency and receive (peer) feedback about their efforts to be able to improve their writing.

Example 2. Embedded writing education in aerospace engineering education

Embedding writing education in engineering education can be realised by collaboration between communication teachers and teachers in the disciplines. That way, the teaching of writing can go hand in hand with engineering projects students are already involved in.

At Delft University of Technology, second-year bachelor Aerospace Engineering students (in groups of 10 students) engage in projects in which they develop simulations in Matlab or Python about real-world problems. They write a research paper about their results and follow five lectures about scientific writing to support them in this writing assignment. Students work in groups of ten to keep the module feasible for both students and lecturers, and to prepare students for working in group settings in their later career.

At the start of the process, groups set up a team charter, including a division of tasks and guidelines on meetings and deadlines. The research paper is written in a group and graded as a group assignment but also contains an individual grading component. The writing module focuses on the general IMRaD (Introduction, Methods, Results and Discussion) structure of academic research papers. Students learn to perform literature research, to use academic sources, and to apply common reference styles for their discipline. They also practice with general structure principles (writing sections, subsections, and paragraphs) and with visualisation of the results in figures and tables. As supportive learning material, students use an e-book about writing in engineering that is available through the university library. Engineering and communication staff grade the texts with rubrics that focus on different criteria: the engineering teachers focus mostly on content aspects and the communication teachers on aspects that deal with writing. The writing grade counts as a partial grade in the engineering module.

Throughout the module, students write and submit parts of their paper, receive formative feedback from the engineering and communication teachers, and engage in peer feedback and self-reflection exercises.

Apart from designing modules that include the three design principles for writing, it is also important to design these modules in a learning trajectory. Stand-alone modules do not sufficiently foster knowledge transfer: students do not apply what they have learned sufficiently to other tasks after they have followed a stand-alone module (van Merriënboer et al., 2025). To make sure that transfer happens, students must have the opportunity to practice with different genres in consecutive years of their study programme, with increasing levels of difficulty. Example 3 shows how this was done in Mechanical Engineering and Civil Engineering programmes in Sweden.

Example 3. The writing programme at Chalmers University of Technology, Sweden

The Centre for Language and Communication at Chalmers University has been engaged in several learning trajectories that support professional and academic

writing for engineers. Gustafsson and Boström (2012) explain how these programmes are set up. Two specifically successful examples are the first and second year of the Mechanical Engineering and Civil Engineering programmes, leading up to the writing of an interdisciplinary BSc thesis (15 ECTS) in the third year of these programmes.

In the first years of these programmes, students engage in reporting their learning outcomes in two modules: 'Introduction to Mechanical Engineering', where students participate in a design project, and the introductory module 'Building in Society in Civil Engineering'. Both lecturers from the Centre and staff members of the department read and assess the reports.

In the second year of the Mechanical Engineering programme, students report about a more demanding design project. Summative assessment criteria for this project, in which criteria about writing are included, were set up in collaboration with lecturers of the Mechanical Engineering department. In the second year of the Civil Engineering programme, students engage in an advanced, writing-oriented module 'Building Economy and Organization'. In this module, focus is on critical reading and argumentation, and the requirements are more demanding.

Of course, it is possible to teach students writing using a standard method. Several online materials or textbooks are available that could support a writing component in engineering projects (e.g., *LabWrite* (North Carolina State University, 2004), *Writing scientific research articles* (Cargill & O'Connor, 2013), and *Writing technical reports for readers with little time* (Elling et al., 2012)). These textbooks are developed by knowledgeable writing instructors and are based as much as possible on evidence-based principles of writing instruction. However, they may not acculturate the students sufficiently in their specific discipline, because they are often generally applicable methods, that may be useful for students from different academic fields.

3.2 Writing in a group

Chapter 2.6 discusses teamwork in an engineering context. This section highlights specific points of attention for writing assignments in groups.

Many engineering programmes provide writing assignments as group projects. Multiple studies indicate that group projects improve student learning and motivation (e.g., Talib & Cheung, 2017). Projects let students combine the strengths and weaknesses of team members and provide internal peer feedback. In addition, group projects prepare students for real-world settings by teaching them to collaborate; an essential skill, as employers value teamwork highly in engineering graduates (Leandro Cruz & Saunders-Smiths, 2019). Group writing assignments can also be more practical than individual assignments. Students can write longer, more substantial documents about subjects they could not otherwise familiarize themselves with. Furthermore, group projects can reduce grading time for lecturers.

However, to prevent the situation where some students take the lead while others lag behind, it is important to support the collaborative writing process. Instructors should

give students instructions to plan the writing process. Gimenez and Thondhlana (2012) highlight the importance of writing process planning, both in engineering practice and among students. This includes three aspects: setting expectations on practical matters; deciding on a consistent aim, structure, and writing style of a document; and the assignment and ordering of various writing sub-tasks.

Furthermore, an individual writing component, peer assessment, and reflective practice about writing can help demonstrate that all individuals contributed meaningfully to the group writing assignment. Individual assignments allow students to show their individual writing competency, for example by having them write a separate short piece or by having them provide insight into the individual contributions to the group writing assignment. In peer ratings, students assess other group members' contributions to the final product or their ability to work cooperatively (Oakley et al., 2004). This assessment may influence the final grade. Instructors can also ask students to reflect on their writing progress, to show how they planned their writing, give insight in their writing process, and how they used LLMs to improve their writing products.

3.3 Feedback as support for the writing process

Whilst Part 3 of this handbook discusses various assessment methods in detail, this section highlights points of attention for giving feedback on written assignments. Scholars (e.g., Haswell, 1983) recommend focusing on one or two aspects of writing. Extensive comments on lower-order concerns, such as spelling and grammar, distract from the main goals of writing. Literature on the efficacy of error correction gives mixed results (Mao & Lee, 2020). For example, extensively marking all errors in a text is not only time-consuming, but also ineffective at improving students' writing abilities: they may not fix similar unmarked errors in their texts or may repeat errors in later writing assignments. Lecturers should keep in mind that they are not a reviewer or editor for their students but should guide their students towards becoming independent writers. Instead, instructors should comment on higher-order aspects, such as audience adaptation and organization. For individual students who struggle with writing assignments, writing centres can provide more personalised and extensive support, thus further reducing instructor workload (Ryan & Zimmerelli, 2010).

Instructors should also refrain from providing exclusively negative comments, which can be discouraging for students. Smith (2008) proposes two alternative methods of providing feedback on writing: rubrics and mitigated criticism. Rubrics (chapter 3.2) speed up the grading process compared to commenting on texts and increase reliability when grading multiple texts. In addition, for students they clarify what level they are at and what areas need more work. Mitigated criticism refers to the practice of providing both strong points and points of improvement. Although more time-consuming, this provides a more personal way of evaluating text and softens the blow that negative feedback could potentially have on students. Smith (2008) found that students vastly preferred either of these strategies over feedback that focused exclusively on the negative points. Taylor (2007) found that such strategies are also beneficial in engineering modules.

Peer review (Chapter 3.2) is another effective, time-saving method of feedback. This offers students an extra round of feedback on their work while limiting the workload for instructors. Students learn not only by receiving feedback, but also by giving feedback (Mulder et al., 2014). Instructors should teach students how to give constructive feedback and how to receive and process feedback. A good way to do this is to connect giving peer feedback to professional peer review processes as they are used in academia and industry.

4 Recommendations for implementation and learning

We would like to present six main takeaways for designing and executing writing education in engineering and for assessing writing.

1. Make sure that writing education is embedded in the engineering discipline, enabling students to become acculturated in their discipline as writers and to familiarize themselves with authentic, realistic genres that are important for their future workplace, be it in industry or in academia.
2. Stimulate cooperation between instructors in the engineering disciplines and instructors of communication. Engineering instructors are necessary to bring in knowledge about genres that are important for their specific field, to highlight the importance of writing in engineering, and to assess if students have acquired the necessary knowledge, as reflected in their writing. Communication instructors are necessary to bring in knowledge about general writing principles and pedagogical practices for the teaching of writing. Together, they can develop rubrics to assess student writing that cover both disciplinary content and writing proficiency.
3. Instead of standalone writing modules, develop well-aligned learning trajectories over different years of the curriculum, to make sure that students can practice regularly with new genres in learning tasks of increased complexity, to create confidence in their writing abilities over time.
4. In writing education, use active learning. Avoid lectures about the theory of writing. Give students the opportunity to practice with writing individually and in groups during lectures, and to improve their writing based on self-reflection and constructive peer and instructor feedback.
5. Assess the outcomes of writing education with well-designed rubrics. Refrain from detailed remarks that focus on mistakes only but make use of mitigated criticism that focuses on strong points that should be maintained and weak points that can be improved.
6. Do not ban the use of LLMs in the classroom, as this is hard to enforce and hinders discussion about the pitfalls of LLMs. Instead, redesign modules to take LLM use into account, and educate students on the responsible use of LLMs.

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AI statement

During the preparation of this work Angeniet Kam made use of Elicit at the beginning of the writing stage, to see which suggestions it gave for literature about writing (instruction) in engineering. Any sources it generated that seemed interesting were then accessed directly and no text that was generated by the AI was used for the chapter itself.

Contributor statement

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2.9

Embedding the Core Triad: Spatial Ability, Visualisation, and Representational Literacy

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Engineers rely on visual-spatial thinking at many stages of practice, from interpreting technical drawings to simulating system behaviour before construction begins. Simultaneously, engineering educators assign complex spatial tasks often without explicitly and deliberately teaching the underlying cognitive skills those tasks demand. This chapter addresses that gap by presenting visual-spatial thinking as a structured, trainable competency built on three interdependent elements: spatial ability (the cognitive capacity to mentally manipulate visual images), visualisation (the active process of applying that capacity to engineering problem solving), and representational literacy (the skill of creating and communicating through engineering’s visual language). Together, these form the Core Triad. The chapter argues that all three elements are essential for engineering practice, demonstrably trainable through targeted instruction, and central to equitable access to the discipline. We present five evidence-based implementation strategies (low-stakes sketching, physical and digital manipulatives, anonymous peer feedback, concept mapping, and dedicated visual-spatial skills modules), along with practical guidance and supporting research evidence. The chapter concludes with a synthesis of teaching recommendations designed to foster the growth-oriented culture in which these strategies are most effective. The overall aim is to equip educators with a coherent framework for developing the Core Triad skills in all students, not only those who innately have them.

1 Definition

Visual-spatial thinking is a core mode of thought in engineering, underpinning how problems are understood, solutions are conceived, and systems are designed (Ferguson, 1992; Kozhevnikov et al., 2007; Raju & Sorby, 2024). An engineer must look at a drawing, a simulation, or a dataset and be able to see the latent behaviour within (e.g., visualising assembly sequences before construction, simulating fluid flow through a valve design, or walking mentally through the ergonomic reality of a design a decade later). Crawley et al. (2014) conceptualise engineering practice as a lifecycle of conceiving, designing, implementing, and operating products, processes, and systems across disciplines. In light of this, visual-spatial thinking could be understood as underpinning multiple stages of engineering design and problem solving, from concept to validation.

Despite its foundational role, visual-spatial thinking often remains an implicit expectation rather than an explicit and deliberate target of instruction (Ha & Fang, 2016; Sorby, 2009). When students struggle, they are frequently viewed as lacking engineering intuition (Newcombe, 2010) rather than as learners who need deliberate training in a distinct and teachable skill set (Sorby, 2009; Uttal et al., 2013). This chapter addresses this disconnect by presenting visual-spatial thinking not as an inherent attribute, but as an active, learnable process structured around the Core Triad of three interdependent elements – namely, spatial ability, visualisation skills, and representational literacy.

Spatial ability is the cognitive foundation, defined as the capacity to generate, retain, and mentally manipulate visual images of objects in two- and three-dimensional space (Buckley et al., 2018; Lohman, 1994). It underlies core engineering tasks such as interpreting technical drawings, manipulating computer-aided design (CAD) models, and supporting the spatial reasoning that runs through engineering practice. Spatial ability is not a fixed trait, as meta-analyses confirm that targeted instruction produces significant, lasting improvements, making it a learnable competency (Uttal et al., 2013).

Visualisation skills are the active, applied processes that draw on spatial ability to construct, interpret, and work with mental images in order to understand and solve engineering problems (Raju & Sorby, 2024; Sorby et al., 2013). This competency is not the simple act of passive observation but an engaged cognitive act that enables an engineer to mentally see how a system behaves before it is built or mentally simulate physical phenomena under conditions not yet tested.

Representational literacy completes the triad by addressing how the above visual-spatial thinking is externalised, communicated, and refined. It refers to proficiency in creating, interpreting, and working flexibly with the visual language of engineering such as via technical drawings, schematics, free-body diagrams, and digital models (Johri & Lohani, 2011). These representations function as cognitive artefacts that make abstract thought tangible and open to critique, revision, and collaboration.

The three elements form a continuous and mutually reinforcing cycle. Spatial ability provides the cognitive capacity that enables visualisation, visualisation is made communicable through representational literacy, and the act of creating and working with external representations in turn strengthens spatial ability.

When a student sketches a 3D component, they simultaneously engage spatial ability (mentally rotating the object), practise visualisation (reasoning and deciding what to emphasise), and develop representational literacy (applying technical drawing and mapping conventions). In other words, a student who can mentally rotate simple geometric forms but struggles to apply this capacity to interpret a complex engineering assembly may have strong spatial ability but underdeveloped visualisation. Similarly, a student who can reason visually but cannot produce an accurate sketch or read a technical drawing may have underdeveloped representational literacy despite strong and intact visualisation. The cycle operates as a unified whole and recognising it allows educators to diagnose precisely where a student may be struggling — whether with internal spatial cognition, the functional applicability of visualisation, or with its externalisation; thus, diagnostic distinction can directly support instructional choices.

We propose the term Core Triad to capture the integrated relationship between these three elements, as existing literature has tended to treat them separately (e.g. Johri & Lohani, 2011; Sorby, 2009). The strategies in Section 3 are designed to support practical fluency across all three elements.

2 Why teach the Core Triad of spatial ability, visualisation, and representational literacy?

The case for deliberate and explicit instruction in the Core Triad rests on three pillars: these skills are essential and are highly associated with success in engineering practice, design, and education (Buckley et al., 2018; Ferguson, 1992; Wai et al., 2009); they are malleable and trainable (Newcombe, 2010; Uttal et al., 2013); and developing them is a meaningful equity strategy that is fundamental to inclusive pathways into the field of engineering (Sorby et al., 2018). Strategies and examples supporting the practical implementations of these pillars are outlined in Section 3.

2.1 Essential for engineering practice and learning

The Core Triad is not an ancillary or subsidiary skill set; it is a fundamental mechanism through which engineering thought operates. Consider a student designing a combustor mock-up. They deploy spatial ability to navigate the nested geometry of casing, liner, injector arrays, and cooling passages; visualisation to mentally simulate assembly sequences and foresee tooling conflicts; and representational literacy to translate this understanding into manufacturing drawings and exploded-view diagrams for collaborators. A failure in any one element (i.e., a misjudged clearance, an unseen assembly conflict, or an ambiguous drawing) renders the overall work unfit for purpose.

Therefore, the pedagogical implication is clear that if the Core Triad is the mechanism of expert practice, instruction must develop this integrated competency deliberately.

Moving fluidly from mental modelling to dynamic visualisation to accurate representation is a cognitive skill (or cycle) that can, and must, be explicitly taught, scaffolded, and practised (Ha & Fang, 2016; Porat & Ceobanu, 2024; Sorby et al., 2013). It cannot be assumed to arrive innately with students, nor to be absorbed passively. As engineering evolves to address interdisciplinary challenges in design and advanced manufacturing, this capacity for visual problem solving becomes more central to innovation and technical mastery (Crawley et al., 2014).

2.2 Malleable, trainable, and consequential

Spatial ability has robust predictive validity in engineering, adding substantial forecasting power over mathematical or verbal aptitude alone, and longitudinal studies confirm that spatial skills in adolescence strongly predict both entry into and long-term success in STEM fields, even after controlling for the other aptitude measures (Berkowitz & Stern, 2018; Wai et al., 2009). For educators, the key insight is that this predictive relationship exists because the spatial skills assessed are the same ones required for successful professional engineering and engineering-related practice (Hegarty, 2010; Lubinski, 2010; Wai et al., 2009).

Meta-analytic evidence demonstrates that spatial skills are malleable and respond durably to structured training (Newcombe, 2010; Sorby, 2009; Uttal et al., 2013). Therefore, they are learnable competencies, not fixed traits. Gains acquired transfer to related cognitive and STEM-relevant task success (Hawes et al., 2022; Sorby et al., 2013; Uttal et al., 2013). The educational imperative is therefore not selection of students who innately possess this skill, but development of this skill in all students.

Spatial ability can be assessed and tracked with a validated instrument such as the Purdue Spatial Visualisation Test: Rotations (PSVT:R) (Yoon, 2011), which is widely used in engineering, CAD, and STEM education (Maeda et al., 2013; Sorby, 2009). Similarly, spatial ability can be captured using the Mental Rotation Test (MRT) (Gómez-Tone et al., 2022; Vandenberg & Kuse, 1978). These tools allow educators to diagnose student needs and measure the impact of instruction.

2.3 A strategy for equity and inclusion

Disparities in spatial skills among entering students often reflect differences in prior opportunity, such as access to spatially rich early activities shaped by early education (Newcombe & Frick, 2010), gender (Liben, 2015), and socioeconomic background (Levine et al., 2005), rather than inherent aptitude. Moreover, disparities may surface due to neurological variation, such as aphantasia (Muraki et al., 2023).

Targeted spatial instruction is therefore a powerful equaliser. The greatest gains from training are often seen among students who start with lower scores (Sorby, 2009; Uttal et al., 2013), and structured interventions have improved retention among underrepresented groups in engineering (Sorby & Baartmans, 2000; Sorby et al., 2018). Explicit development of the Core Triad is therefore a proactive strategy for widening access and ensuring that pathways into engineering are opened, not narrowed, by the training we provide (Hsi et al., 1997; Sorby et al., 2018; Stieff & Uttal, 2015).

3 Forms of implementation

Instruction in the Core Triad is most effective when it also accounts for the affective context in which students encounter visual-spatial tasks. Many engineering students experience perfectionism (Al Kakoun, 2023; Al Kakoun et al., 2024), anxiety (Brotherton et al., 2025), or a fixed-mindset belief about their ability (Stump et al., 2014; Yeager & Dweck, 2012). This may lead them to mistakenly believe that visual-spatial ability is an innate gift rather than a trainable competency, causing fear-based frustration or avoidance when confronted with tasks such as mental rotation or diagram interpretation. Stereotype-based attributions for the gender gap in spatial tasks have similar performance-hindering effects (Moè, 2012). These projections are not signs of low ability, but barriers to engagement that structured teaching can directly counter. Further, cognitive science indicates that aphantasia (reduced or absent voluntary mental imagery) affects roughly 4% of the population (Dance et al., 2022), with implications for how mental imagery and embodied simulation are exercised during conceptual processing (Muraki et al., 2023). In engineering education, this should be taken into account during instructional design if the aforementioned projections are voiced in class, for example via emphasising representational literacy (Bainbridge et al., 2021).

Each strategy below is designed both to build the skills of the triad and to dismantle the affective barriers that prevent students from engaging with them.

3.1 *Low-stakes sketching and iterative prototyping*

Rationale

This strategy counters perfectionism and avoidance by making the iterative process, not the polished product, the explicit goal of visual-spatial tasks. Short, low-stakes exercises reduce emotional risk, encourage engagement without the paralysis of perfectionism, and embody a growth-oriented approach; for example, emphasising the quantity of sketches demonstrates that the skill can be built through practice (Johri & Lohani, 2011; Yang & Cham, 2007), and is not innate.

Practical implementation

Integrate short, focused sketching drills into your module using pen and unlined paper, as this discourages erasing and signals that generating multiple rough sketches is part of the work. Adapt exercises to discipline; for example, in structural or civil engineering, students might sketch a force-flow path through a truss node, whereas in mechanical or aerospace engineering, a quick isometric view of a bracket or flange may be drawn. Moreover, model your own thinking by narrating your reasoning, decisions, and corrections as you sketch. Your feedback should target the clarity of the engineering concept, not artistic quality, and peer review should be scaffolded with prompts such as: *‘What relationship in this sketch is communicated clearly?’* or *‘What question does this diagram suggest to you?’* This strategy builds spatial ability through mental manipulation, externalises visualisation for refinement, and practises the conventions of representational literacy in a low-risk environment. Table 2.9.1 summarises the dos and don’ts for efficiently implementing this strategy.

Table 2.9.1: Guidelines for low-stakes sketching and iterative prototyping

<i>Do's</i>	<i>Don'ts</i>
Use pen-based computing or pen and unlined paper and embrace iterative drafting.	Grade for neatness or penalise exploratory, messy sketches.
Frame sketching as engineering communication or visual thinking.	Allow for the ' <i>I can't draw</i> ' narrative to become an opt-out option.
Design activities with multiple valid solutions or representations.	Present a single correct sketch as the only goal.
Give feedback on logical clarity and engineering content.	Criticise early, rough drafts as wrong.
Model your own sketching process with a think-aloud narration that includes corrections.	Present solutions without co-construction or reasoning aloud.

Example 1. The foundational spatial skills programme at Michigan Tech

In the foundational spatial skills programme at Michigan Tech, students using multimedia software combined with guided workbook sketching showed significantly greater gains on the PSVT:R than those using software alone. The finding remained consistent across multiple cohorts and underpins the programme's core principle, that is, sketching 3D objects greatly enhances spatial skills (Sorby, 2009).

3.2 Physical and digital manipulatives for embodied learning**Rationale**

Manipulatives ground abstract spatial transformations in tactile experience and real-time visual feedback. They reduce cognitive load by offloading mental work onto the physical environment, making spatial relationships concrete and observable. This approach provides compensatory pathways that are particularly valuable for students who find purely internal visualisation difficult.

Practical implementation

Begin with simple geometric solids to practise foundational mental rotation, then progress to authentic engineering components (valve bodies, linkage arms, printed circuit boards). Crucially, pair the physical act with a cognitive task; for example, after manipulating an object, have students sketch it from a new orientation or predict its cross-section. Then, use digital tools as complementary layers, such as augmented reality (AR) applications or sensor-embedded models that synchronise physical rotation with virtual display and powerfully demonstrate the connection between physical rotation of an object and its orthographic projections or internal

structure/mechanics as it rotates (Fang et al., 2022; Gómez-Tone et al., 2022). For remote contexts, encourage household objects, like modelling clay and building blocks, for initial tactile exploration. Lastly, ground these tasks in engineering contexts, and frame each activity with clear reasoning questions such as *‘How does the meshing (or the cross-section) of these gears change if I rotate this shaft?’*. This strategy strengthens spatial ability through embodied cognition, provides a concrete scaffold for visualisation, and allows students to test and verify mental manipulations externally. Table 2.9.2 summarises the do’s and don’ts for efficiently implementing this strategy.

Table 2.9.2: Guidelines for physical and digital manipulatives for embodied learning

<i>Do’s</i>	<i>Don’ts</i>
Pair physical manipulation with a follow-on task like a sketch or reasoning from a new viewpoint.	Use manipulatives without a clear analytical learning objective.
Progress from simple geometric shapes to authentic, industry-relevant components.	Rely solely on abstract shapes or disconnect activity from engineering contexts.
Use digital simulations to reveal hidden features (internal cutaways or force vectors) that physical objects cannot show.	Use digital simulations alone when a physical object would provide richer tactile and proprioceptive feedback.
Frame the manipulative as a valid external workspace and validate multiple pathways to understanding and externalising visual-spatial cognition.	Assume all students are building the same vivid internal image.

Example 2. Learning gains on the PSVT:R

In a controlled study with second-year engineering students, a group training with 3D-printed engineering components embedded with sensors, who visualised the physical rotation alongside a precisely rotated virtual model, achieved normalised learning gains of 41.2% on the PSVT:R after five weeks, compared to 8.2% for a control group. Gains increased when authentic engineering components were used in place of generic shapes, demonstrating that student motivation and interest are enhanced when spatial training is contextually meaningful (Fang et al., 2022).

Example 3. AR-supported spatial training sessions

In a study with first-year Civil Engineering students, an experimental group completed five two-hour, AR-supported spatial training sessions using a physical workbook, webcam, AR software, and fiducial markers (i.e., printed markers that the webcam can recognise, prompting the AR software to display the 3D model

associated with the 2D visual or exercise in the workbook). When the workbook markers were shown to the camera, students could visualise the corresponding 3D object, helping them move between orthographic drawings, spatial relationships, missing views, and hand-sketched 3D constructions. After the intervention, students showed significant gains on spatial ability tests, including the MRT, and achieved significantly higher final grades than the control group in Technical Drawing and CAD, Physics, Calculus, and Linear Algebra. The study demonstrates how AR can be used as a structured scaffold for repeatedly connecting 2D representation, 3D visualisation, and manual sketching in early engineering education (Gómez-Tone et al., 2022).

3.3 Anonymous peer feedback to build confidence

Rationale

This strategy addresses performance anxiety and perfectionism by creating a psychologically safe environment for sharing preliminary work. Anonymity lowers the emotional risk of exposing imperfect sketches, and structured feedback protocols shift focus from the individual to the engineering content of the work produced. It teaches students to critique visual representations constructively, deepening their representational literacy while fostering a collaborative, growth-oriented culture and — an essential factor — disconnecting the work produced from the person(s) who produced it.

Practical implementation

Integrate regular, low-stakes opportunities for anonymous submission and critique. Peer assessment in higher education has been shown to improve academic outcomes (Double et al., 2020; Nicol et al., 2014), and anonymous peer review specifically can reduce evaluation apprehension and encourage candid engagement with visual work (Rotsaert et al., 2018; Vanderhoven et al., 2015). Use accessible tools (like shared digital whiteboards such as Miro, polling software such as Mentimeter) and pen-based or digital sharing tools (Johri & Lohani, 2011) to ensure anonymity is effortless and efficient in large classes. Begin with students anonymously submitting a draft solution (e.g., a force diagram, a conceptual sketch, a first attempt at a graph) and display submissions without attribution. Then, provide objective prompts to guide feedback; for example, ask: *‘Identify one relationship communicated very clearly here’* or *‘What one question does this sketch raise?’* You may also model this feedback language yourself and publicly celebrate insightful observations, reinforcing that the goal is collective understanding, not ranking or connecting a student’s identity with the work produced. This ritual builds the habit of separating the creator from the creation, making critique a psychologically safe standard part of engineering practice.

This strategy primarily supports representational literacy by training students to analyse and critique visual communications for clarity and accuracy. By lowering anxiety and mitigating perfectionism, it enables more free engagement in the cognitive

work of spatial and visual thinking and promotes constructive and psychologically safe, anxiety-free developmental learning.

Example 4. Pen-based computing system

Johri and Lohani (2011) implemented a pen-based computing system (Tablet PCs with DyKnow software) across Virginia Tech's first-year engineering module involving approximately 1500 students. Survey data from 525 students revealed that 73% agreed that the technology effectively contributed to their learning, specifically by moving them beyond passive copying to active, collaborative knowledge construction. The anonymous sharing feature was attempted to reduce student embarrassment and build confidence in the process of visual representation.

3.4 Structured concept mapping for visual synthesis

Rationale

Concept mapping develops representational literacy and combats cognitive rigidity by requiring students to actively structure knowledge and articulate relationships visually. The absence of a single correct map encourages cognitive flexibility, reduces anxiety about finding a single right answer, and makes implicit mental models explicit and open to refinement. A concept map becomes a visual plan of attack for tackling analytical problems, making the logical pathway explicit before calculations begin.

Practical implementation

Introduce concept maps as tools for synthesis and problem-solving planning, not just recall. Begin with a focused prompt such as '*map the key variables and governing principles for a closed thermodynamic system*', or '*visualise the relationship between concepts from last week's stress analysis module*'. Use concept mapping software (e.g., CMapTools, draw.io) or digital whiteboards that allow easy rearrangement; this emphasises the malleability of knowledge structures and lowers the barrier to iteration. The process works well across three phases: 1) guided co-construction of a master map in class, with you modelling linking phrases that encode engineering relationships (e.g., '*is resolved by*' rather than '*related to*'); 2) annotation of the master map for a specific problem, numbering calculation steps, and highlighting the critical path; and 3) adaptation to a novel problem, requiring students to modify their map to account for new variables and demonstrating genuine conceptual transfer. Facilitate a gallery walk for map comparison, where students defend their structural choices and question each other's connections.

This strategy primarily strengthens representational literacy by teaching students to create and interpret a formal diagrammatic system (i.e., nodes, links, propositions). It directly supports visualisation by forcing an active, relational organisation of concepts, which is the foundational mental model for effective problem solving. Table 2.9.3 summarises the dos and don'ts for efficiently implementing this strategy.

Table 2.9.3: Guidelines for structured concept mapping for visual synthesis

<i>Do's</i>	<i>Don'ts</i>
Frame mapping as a formative tool for organising thinking, not a summative test of facts.	Present a single correct map as the only goal.
Use software that allows easy rearrangement to encourage iterative structuring and exploration.	Grade based solely on the number of nodes or superficial features.
Have students compare and defend their map structures in small groups.	Dismiss a student's map structure without exploring their rationale.
Use mapping to visually integrate topics and reveal the conceptual big picture.	Use mapping only at the end of a topic as a static summary.
Encourage cross-links that represent complex or causal relationships.	Focus feedback only on hierarchical correctness at the expense of novel and innovative connections.

Example 5. Students' reported confidence in engineering skills

In a sophomore Continuum Mechanics module at Smith College, USA, Ellis et al. (2004) embedded two concept maps throughout the curriculum: a module-level map relating material, geometry, loading, force, and stress, and a focused dynamics map for rigid-body problem solving. Across the semester, students' self-reported confidence in their engineering skills rose from 11% pre- to 81% post-intervention ($n = 27$). Concept maps were one of several pedagogical practices contributing to this gain, and students described the maps in focus groups as helping them see 'the big picture'.

3.5 Dedicated spatial skills module for intensive intervention

Rationale

For institutions with sufficient resources, a dedicated module provides the most structured pathway for building foundational spatial competencies (Porat & Ceobanu, 2024; Sorby, 2009). It creates a focused space where spatial thinking is the sole objective, enabling systematic Core Triad skill progression without the simultaneous pressure of complex engineering content. This approach is particularly effective as an equity intervention, as it provides intensive foundational support before students encounter failure in core curriculum modules, functioning as an academic catalyst.

Practical implementation

Begin with a validated diagnostic (e.g., using the PSVT:R) in the first week of a linked gateway module (e.g., Engineering Graphics), framed positively as an opportunity to identify areas for foundational development. Invite students scoring below a set threshold to enrol, framing this clearly as a meaningful investment, not a remedial

placement. Structure the curriculum around deliberate skill progression from 2D to 3D thinking (i.e., transitioning from multi-view projections to auxiliary views, to mental rotation, to cross-sections), using hands-on sketching and physical model work as primary activities (e.g., sketching or physical model manipulations), with CAD or AR software as a complementary reinforcement layer once manual skills are established. Continually connect exercises to authentic engineering contexts (such as real component drawings, assembly sequences, and industry-relevant tasks) to maintain relevance and motivation.

Table 2.9.4: Ten-week spatial skills module

<i>Module focus</i>	<i>Key activity</i>	<i>Skills targeted</i>	<i>Deliverable</i>
<i>Weeks 1-2</i> 2D-3D translation	Isometric sketching from coded plans, and orthographic projection of simple blocks.	Spatial visualisation and mental projection.	Set of five isometric and orthographic sketch pairs.
<i>Weeks 3-4</i> Surface and solid manipulation	Sketching cross-sections, surfaces of revolution, combining primitives.	Mental rotation and spatial relations.	Cross-section drawings of combined solids.
<i>Weeks 5-6</i> Folding and pattern development	Paper-folding exercises; unfolding 3D objects to 2D nets.	Mental folding and spatial transformation.	Completed workbook exercises.
<i>Weeks 7-8</i> Connecting to CAD	Recreating hand-sketched objects in basic CAD software.	Reinforcing mental models through digital representation.	Simple 3D CAD model files.
<i>Week 9</i> Applied engineering context	Sketching and modelling a multi-part assembly (e.g., flange coupling or gear assembly).	Integrated visualisation and representational literacy.	Assembly sketch and basic CAD assembly.
<i>Week 10</i> Review and post-assessment	Final skills review; re-administer diagnostic.	Measure growth and reinforce mastery.	Post-test score and final portfolio submission.

This strategy builds all three elements of the triad systematically, establishing foundational spatial ability, deliberate visualisation processes, and fluent

representational literacy as core curriculum. Table 2.9.4 outlines a ten-week progression that implements this approach.

Example 6. Interventions for low-scoring students

Michigan Tech's required module for students scoring below the PSVT:R threshold uses sequenced activities in sketching, projection, and rotations (Sorby, 2009). Across cohorts, the intervention has produced substantial PSVT:R gains and acted as an equity intervention: retention was higher among women who enrolled in the module than among those who did not, at 76.7% compared with 47.8%, respectively (Sorby, 2009); this is noteworthy, as women are almost three times as likely as men to score below the threshold (Sorby et al., 2013). Other students who had taken part in similar interventions subsequently also performed significantly better in gateway modules, including Calculus (Sorby et al., 2013). These examples demonstrate how such interventions are effective for engineering students in general, and for women engineering students in particular, supporting the strategy of inclusion and equity discussed in Section 2.3.

4 Recommendations for implementations and learning

The five strategies described above form a tiered model for action. Their effectiveness, however, depends on the broader teaching environment in which they operate. Table 2.9.5 synthesises the core pedagogical shifts required, replacing environments that inadvertently reinforce anxiety and fixed-mindset thinking with those that deliberately foster growth, flexibility, and psychological safety.

Beyond this cultural foundation, four practical recommendations apply across all five strategies. First, use a validated diagnostic assessment (e.g., PSVT:R) at the outset of a module to identify students who would benefit most from foundational support, and/or diagnose where (within the Core Triad skillset cycle) students may be struggling; then use post-intervention assessment to measure growth and validate the intervention. Second, sequence from concrete to abstract (or vice versa) in all activities; begin with physical or hands-on manipulation before moving to digital or purely mental tasks. Third, connect every exercise explicitly to engineering outcomes to make the professional relevance of each spatial task visible to students before they begin, and resist treating any exercise as a warm-up that needs no justification. Fourth, collect longitudinal data in higher-level modules to validate the impact of any intervention, refine the approach over time, and build an institutional case for continued investment.

Finally, in addition to referenced literature in this chapter, we recommend Newcombe (2017), Sorby (2011), Sorby and Panther (2020) and Wang et al. (2025) for those of you who want to deepen their knowledge further.

Table 2.9.5: Teaching practices for fostering a growth mindset in visual-spatial learning

<i>Do's</i>	<i>Don'ts</i>
Frame challenges as skill-building and as cognitive workouts.	Praise innate talent (i.e., use language like ' <i>you're a natural</i> ') instead of effort and strategy.
Normalise struggle and iteration and share your own early drafts and corrections as an educator.	Expect perfect first drafts that validate perfectionism and penalise the exploratory work that is vital for learning.
Focus feedback on process and progress and comment on the improvement from first to second sketch.	Grade only the final product's neatness, since this incentivises hiding the learning process.
Offer different ways to demonstrate understanding (for example, a sketch, a physical model, or a verbal description).	Present only one correct visual solution; discourage messy creative problem solving.
Use low-stakes, frequent practice integrated throughout the module.	Rely on one high-stakes assessment, since this turns it into a test of fixed ability rather than a developing skill.

5 Concluding summary

This chapter has presented visual-spatial thinking as a central, trainable competency in engineering education, structured around the interdependent Core Triad of spatial ability, visualisation, and representational literacy. The evidence reviewed establishes that these skills are not innate characteristics, but a dynamic foundation that structured instruction can develop in all students, and that doing so is both an educational imperative and a meaningful equity strategy.

Implementing this vision requires a cultural shift, from assuming visual fluency to deliberately building it. The five strategies outlined in Section 3, from low-stakes sketching to dedicated spatial modules, provide a practical toolkit for educators to implement in their classrooms. The teaching mindset synthesised in Section 4 provides the conditions under which those tools are most effective. Together, they support educators in cultivating engineers who are not only proficient analysts but fluent spatial-visual thinkers, and designers who translate mental models into reality, problem solvers who see system behaviour before it is built, and collaborators who communicate complex ideas with precision. By deliberately making the implicit explicit, engineering educators can build an inclusive foundation for the innovative solutions the future demands.

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AI statement

During the preparation of this work, the authors used Claude and ChatGPT in order to check and correct grammatical errors, punctuation, and/or improve sentence clarity. After using this tool, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

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2.10

Teaching Interpersonal Communication: Listening, Adaptive Communication and Interconnection Skills

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This chapter helps you teach interpersonal communication skills for engineering students. It focuses on one-to-one interactions based on three skills: active listening (perceiving and interpreting verbal and non-verbal messages), adaptive communication (integrating perspectives to negotiate meaning and adjust communicative choices), and interconnection (building and sustaining constructive professional relationships over time). For each skill, we define subskills and provide implementable teaching guidance, including activities, short practice drills, and feedback and reflection prompts that support transfer into project work, stakeholder engagement, and interdisciplinary collaboration. Interpersonal communication does not succeed or fail only at the level of technique; emotion cues, competing perspectives, and identity-based dynamics shape what people notice, how they interpret it, and what feels permissible to say or do. To assist in the operationalisation of these concepts, we pair each interpersonal communication skill with a social dimension: social emotions help students identify affective cues that guide attention and inference in listening, perspective taking helps students to surface and to work with divergent framings in adaptive communication, and social identity helps students anticipate trust and status dynamics that shape interconnection. This chapter will help you teach students to predict, avoid, and repair communication breakdowns by choosing appropriate learning scaffolds, and designing activities and assessment that treat interpersonal communication skills as part of professional engineering competence.

1 Definition

Interpersonal communication refers to the ability to exchange information, perspectives, and emotions effectively with others to achieve mutual understanding and collaboration (see Hargie, 2021). Drawing on research on transferable competencies in engineering education (Leandro Cruz & Saunders-Smiths, 2022), we conceptualise this ability through three interrelated skill areas:

1. Active listening skills: attending closely to verbal and non-verbal messages to ensure accurate interpretation.
2. Adaptive communication skills: reflecting on one's own and others' perspectives to adjust communication choices to create shared meaning.
3. Interconnection skills: building trust and sustaining constructive relationships over time.

Together, these communication-specific components of broader interpersonal competency reinforce one another: listening provides the cues, adaptive communication uses them to negotiate meaning, and interconnection sustains the trust that strengthens listening and adaptation over time.

2 Why teach interpersonal communication skills?

Engineering work increasingly relies on inter- and transdisciplinary collaboration for technology development, bringing together technical, social, organisational, and lived expertise to anticipate impacts and prevent harm. This emphasis is also reflected in European accreditation: the EUR-ACE framework defines programme outcomes across learning areas that include communication and team-working skills and the capacity to make judgements that incorporate relevant social and ethical issues (ENAAEE, 2021). The need for these skills is most visible in interdisciplinary project teams, stakeholder and client engagement, safety-critical handovers, and design reviews where disagreement must be handled constructively. When interpersonal communication is assumed rather than taught, concerns and uncertainty are left unsaid or are misread (listening), misunderstandings persist across disciplines, languages, and priorities (adaptive communication), and trust erodes so conflict increases or becomes personal, resulting in rising coordination difficulties (interconnection).

The need to teach these skills is further reinforced by evidence that the competencies of engineering graduates in this area often fall short of employers' expectations (Coffelt et al. 2024; Mills & Treagust 2003; Nair, et al., 2009), which has been shown to negatively impact engineering projects (Gamil & Abd Rahman, 2023; Vaghela & Kaushal, 2025; Yang et al. 2025). These skills are considered essential in establishing and maintaining human relationships (Spitzberg & Cupach, 2011) and are fundamental to well-being and ethical engineering practice. Because interpersonal communication is always embedded in broader social contexts, we link each skill to a social dimension — emotions, perspectives, and identities — to clarify how these dynamics shape communication processes and learning opportunities in engineering education.

3 Forms of implementation

Interpersonal communication involves more than exchanging words; it is shaped by emotions, beliefs, and perspectives. Developing these skills therefore requires structured opportunities to notice what is happening in an interaction, to try alternative moves, and to reflect on their effects. The skills of active listening, empathy, and social influence, all relevant to interpersonal skills, are skills that are important now and, in the future, (World Economic Forum, 2025). However, engineering education research has demonstrated that activities requiring interpersonal skills are insufficient to build competence without structure that supports skill development (Picard et al., 2022). Building on findings that interconnection and adaptive communication are common weaknesses (Leandro Cruz & Saunders-Smiths, 2019), we emphasise three levers: (a) structured practice, (b) explicit conceptual models and strategies, and (c) guided reflection. The 3T PLAY framework (Fig. 2.10.1) provides a practical lens for designing and auditing learning activities (Isaac & de Lima, 2024), as modelled in sections 3 and 4 of this chapter.

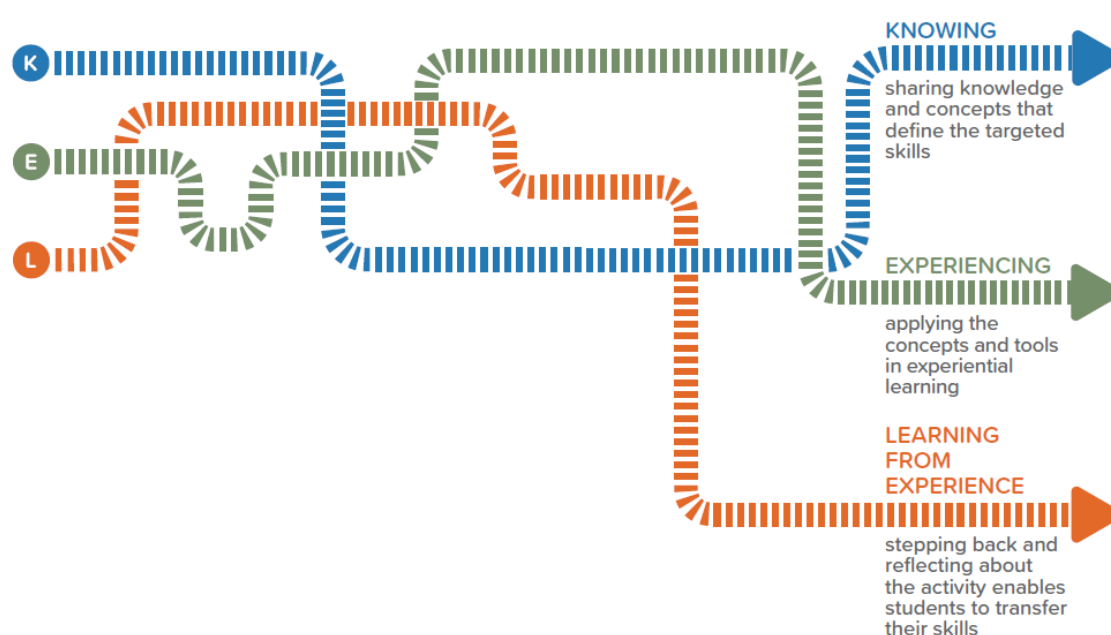


Figure 2.10.1: The 3T PLAY framework (Isaac & de Lima, 2024)

To convert opportunities into learning, you should state dual learning goals (disciplinary and interpersonal), provide a model or strategy before practice (e.g., responses to fear emotions include fight, flight, or freeze reactions), stage short drills before complex projects, and embed reflections after each interaction. Assessment and incentives should be aligned with collaboration (e.g., rubric criteria for listening, adaptation, and relational contribution) and decisions about module organisation (what is graded, time pressure during assessment tasks, team composition) should be checked for contradictions with the competence goals.

Learning does not occur in a vacuum, so the didactic setting should balance challenge with support (Peters et al. 2024). Team projects — especially when they involve several disciplines or stakeholders — create context-authentic friction, and that friction can be productive if students benefit from clear success criteria and strong communication strategies. Recognising that students' learning is impeded when they encounter too much difficulty (Kalyuga 2007; Kirschner et al. 2006) has led to some instructors seeking to reduce these difficulties (Yu & Zin, 2023). However, we argue that difficulties are valuable learning opportunities when they are scaffolded: they prompt students to apply their interpersonal communication strategies and to reflect on their experience. It may even be pedagogically beneficial to deliberately provoke moments of discomfort and irritation to create learning opportunities (Bjork & Bjork, 2023).

Crucially, insufficient preparation and support can overwhelm some students (Ellingsen et al., 2021), sometimes hardening boundaries against other perspectives (Paolini et al., 2024). You can keep conflict educational rather than corrosive by sequencing from low-stakes exercises to more complex project work, sharing explicit discussion norms and repair protocols, giving rapid formative feedback, and ensuring assessment aligns with the collaborative behaviours you are targeting (Hmelo-Silver et al., 2007). In Sections 3.1-3.3, we define teachable sub-skills for each of the three skill areas of active listening, adaptive communication, and interconnection, and illustrate how you can operationalise them through short routines and worked examples.

3.1 Listening: ability to hear and interpret another person's message, enabling a coherent response to both cognitive and emotional components

Listening skills involve capturing what another person is expressing — not only the literal meaning of their words but also what remains unspoken and the emotional messages conveyed through tone, pauses, and body language. Active listening goes beyond hearing; it also includes response strategies that signal attentiveness and help build mutual understanding.

Listening sub-skills

- 1a. Distinguish emotional and cognitive components in another person's communication, attending to both what is said and left unsaid.
- 1b. Identify emotional states and potential implications for both self and other people.
- 1c. Respond coherently to another person's messages, including explicit and implicit aspects.
- 1d. Employ active listening strategies to convey that you are listening and promote mutual understanding.

By distinguishing listening subskills, we make explicit how listening moves from detection to response: 1a) noticing cognitive and emotional content; 1b) interpreting emotions and one's own reactions; 1c) responding coherently to both layers; and 1d) using verbal and non-verbal signals that show the speaker they have been heard.

Together, these sub-skills move listening beyond content capture toward interaction-ready understanding. Example 1 presents a weekly check-in and reflection routine used in a master-level module at the École Polytechnique Fédérale de Lausanne (EPFL) that provides scaffolded support for interpersonal communication skills.

Example 1. Emotion check-in and reflection routine

This example stems from the module How people learn: Designing Learning Tools by N. Kotluk and R. Tormey

Purpose

This routine scaffolds listening skills by helping students notice and label affective cues that shape attention, inference, and turn-taking during interaction.

How to facilitate the activity with students

- 1. Set the target: Remind students of the objective and name the listening focus (e.g., "today we practise noticing and labelling emotional cues that affect how we interpret each other"). Ask each student to name their current emotional state; offer vocabulary support (e.g., Plutchik emotion wheel).*
- 2. Practise (embedded during activities): During class work, pause briefly to ask what students are noticing emotionally (in self and others). Normalise strong emotions as expected in inquiry work and offer a regulation script (e.g., name, normalise, navigate) so discomfort is engaged rather than avoided.*
- 3. Close and transfer: End class with an individual micro-reflection where students write one sentence linking one cue to one communicative move to one action to carry into the next team meeting (e.g., "When I notice X, I will Y").*

Why it works

- Makes the skills visible: You name the listening sub-skill and connect it to collaboration (teamwork now; stakeholder/safety culture later).*
- Creates low-stakes rehearsal: Vocabulary support + brief check-ins operationalise detection and labelling, while the regulation script keeps discomfort within constructive limits.*
- Fosters transfer: The closing reflection links a concrete moment to a specific next move, increasing carry-over into future interactions.*

What this shows

You can turn routine check-ins into listening practice when you name the skill, support cue-labelling, and close with a cue.

Social emotions — those arising specifically from interactions with others — signal and calibrate attention, inference, and action during talk. Micro-cues, including facial tension, tone shifts, and hesitations, convey status, social safety, and belonging, and allow listeners to use these cues to decide whether to explore, defend, or disengage (Tormey, 2021; van Kleef & Côté, 2022). Social emotions matter because they supply the input that drives detection 1a), identification 1b), responding 1c), and enactment

1d) of these interpersonal communication sub-skills. If engineering students ignore or misread these inputs, subsequent communication processes are impeded, leaving students unable to respond effectively. The implication for the development of engineering students' transferable skills is straightforward: students' capacity to capture the meaning and intention of others depends on better interpretation and use of social-emotional information.

In settings where students have had limited prior instruction in listening and where emotion talk is discouraged, some students accurately track technical content while missing or dismissing affective cues interactions. This can collapse cognitive and emotional strands into a single reading of the interaction, increasing the risk of misaligned responses. When students begin to notice the presence of emotional components, their accuracy in decoding this aspect often lags behind their perception, with the result that mislabelling of emotions is common. For instance, pride is read as arrogance, or frustration as hostility. This mislabelling undermines trust and mutual communication even when the technical message is clear (van Kleef & Côté, 2022). In engineering education, local norms that frame emotion talk as irrelevant or inappropriate exacerbate this tendency toward emotional neglect (Krivoshchekov et al., 2025), leaving students' responses hesitant and their listening signals mechanical rather than contingent on accurate interpretation.

Where academic and engineering climates are more psychologically safe, students label peers' feelings more accurately and use those appraisals to guide their responses. Video-ethnography of Nordic sustainability design teams suggests that low-intensity social emotions such as curiosity, comfort, and validation support the sharing of uncertainty and more effective knowledge distribution. Furthermore, acknowledgement and appreciation co-occur with broader participation and more flexible problem solving (Holmén & Lönngren, 2025). At this stage, detection, decoding, and integration of cognitive and emotional components become more reliable, although translating insight into timely action (e.g., reframing a task, clarifying roles, redistributing workload) may still require explicit norms or permission structures.

Expert listening adds judgement about the authenticity and relevance of both cognitive and emotional signals and converts that appraisal into appropriate action. Evidence from emotions-as-social-information theory suggests that authentic enthusiasm or compassion can elicit complementary prosocial behaviour (e.g., offering help, adjusting plans, clarifying misunderstandings), whereas surface-acted displays erode trust and limit coordination (van Kleef & Côté, 2022). Expert listeners integrate cognitive and affective layers across the four subskills: they read the room, adapt their participation, and offer precise reassurance while signalling attention. In design discussions, when vulnerability can be voiced and met with care, teams have been observed to move into deeper exploration of complex issues (Holmén & Lönngren, 2025), illustrating how interpersonal communication supports substantive engineering work.

3.2 Adaptive communication skills: ability to reactively adapt one's communication approach and language in accord with a purpose, context, and individual

Adaptive communication skills involve adjusting how you frame a problem, choose language, and respond in real time so that people can build a shared understanding between their different perspectives. These skills require engineers to recognise that communication styles and knowledge priorities vary by context, professional role, identity, and discipline, and implement their skills to deliberately shape interaction to reduce misunderstandings and to integrate diverse inputs into a workable problem definition. In engineering, this matters because the 'problem solver' identity and the expectation that problems have clear solutions can narrow what counts as relevant knowledge (Isaac & Shew, 2024).

Adaptive communication sub-skills

- 2a. Acknowledge the incompleteness of knowledge sets.
- 2b. Recognize the values, norms, and biases that are active in a communication partner and oneself.
- 2c. Adapt one's language and communication style to reduce misunderstandings.
- 2d. Explicitly integrate different knowledge sets and perspectives.

Example 2. provides a short, low-stakes activity for developing adaptive communication skills based on the 3T PLAY framework; it has been implemented in six countries, including for a first-year design module with 1000 students. The activity addresses skills for managing emotions during peer feedback, supporting listening (1a-1d) and adaptive communication (2b-2c) when feedback is difficult to give or receive.

By distinguishing adaptive communication sub-skills, we make explicit how adaptation moves from epistemic humility to integration: 2a) treating our own perspective and disciplinary knowledge as partial; 2b) noticing the assumptions and biases shaping an interaction; 2c) choosing wording and framing that builds shared meaning (e.g., defining terms, acknowledging another's perspective, checking interpretations); and 2d) integrating multiple perspectives into a broader account of the situation.

A useful lens for developing adaptive communication is the recognition that knowledge is produced within specific contexts — each with its own assumptions, rules, and priorities — which makes any single perspective inherently incomplete (Haraway, 1988). For example, engineering problem framing often prioritises feasibility, efficiency, and innovation, while other priorities (e.g., social justice) may be backgrounded (Faulkner 2007). This is why responsible technology design increasingly relies on inter- and transdisciplinary collaboration to anticipate downstream impacts and prevent harm (Grunwald, 2011). In such collaborations, misunderstandings and irritation are not only barriers; they can be diagnostic cues that reveal conceptual differences and signal where adaptation is needed (Galison 1997; Nicolescu 2002).

Example 2. Emotional self-management practice

This example on emotional self-management practice during feedback discussions, shows how to support students giving each other constructive feedback, especially when it is difficult to receive (Isaac & de Lima, 2024).

Purpose

This routine scaffolds emotional self-management by creating a challenging collaboration situation followed by a low-stakes opportunity to hold peer feedback discussions focusing on emotional skills.

How to facilitate the activity with students

- 1. Set the target: Present the learning objectives related to structuring peer feedback and managing their own and others' emotions during difficult discussions. Have students briefly review their past experiences with peer feedback, focusing on barriers and accelerators including emotions.*
- 2. Practise: Provide students with strategies for managing emotions and giving and receiving feedback. Then set students to work in groups designed to create collaboration difficulties while building a marble run with limited resources. Students then prepare verbal feedback for their partner. Students are encouraged to get out of their comfort zone by sharing at least one point of feedback that feels difficult to receive.*
- 3. Close and transfer: Ask students to analyse what was difficult, constructive, or surprising, identifying one emotion management strategy to use in the future.*

Why it works

- Defining the competence and why it matters now and in their future career clarifies expectations and supports students to set their personal development goals.*
- Analysing their past experiences enables students to see value and challenges in skill development.*
- Simple emotional regulation strategies provide a conceptual model and practical guidance for feedback discussions. Informing students that their emotions are a common, even desirable, part of collaborative work normalises feelings in engineering.*
- Focus on skill development without pressure via short, non-technical activity avoids implication for grades or project deliverables. It also creates space to engage with discomfort and focus on learning.*
- Considering how this feedback and emotional experience was (dis)similar to their projects assists students to transfer their developing skills to future situations.*

What this shows

You can make adaptive communication skills teachable when you 1) name the interaction risk (defensiveness, ambiguity, perceived threat); 2) provide a short

script for regulating emotion and adapting wording; and 3) give students practice opportunity followed by reflection that links one cue to one repair move.

In settings where students have had limited experience communicating across disciplines or roles, some may treat their own framing as self-evident and interpret disagreement as error or resistance rather than conceptual difference. This can produce predictable breakdowns: key terms remain undefined, assumptions are not tested, and feedback is delivered in ways that trigger defensiveness rather than revision. In engineering cultures that reward certainty and speed, the hurdle for recognising incompleteness (2a) and surfacing assumptions (2b) can be high (Faulkner, 2007).

Where learning environments legitimise uncertainty and offer explicit interaction norms, students are more likely to treat disagreement as information and to use it to compare concepts, express uncertainty, and adapt language (2c). At this stage, students begin to translate meta-awareness into practice by reducing jargon, checking interpretations, and signalling openness — especially when cues such as hesitation, irritation, or withdrawal are treated as prompts for clarification rather than as interpersonal failure (Keestra, 2017).

Expert adaptive communication involves integrating perspectives into a shared understanding that guides action (2d). Tools such as concept mapping (Tan et al., 2021) and scenario techniques (Pöbneck et al., 2024) support this integration by making assumptions visible and enabling teams to articulate how different priorities interact. Recognising that no single perspective can fully capture a complex sociotechnical situation provides a strong foundation for adaptive communication in interdisciplinary and stakeholder-facing engineering work.

3.3 Interconnection skills: ability to build and retain professional relationships

Interconnection skills involve building and sustaining working relationships that support learning, coordination, and professional growth over time. In engineering, these skills help students move from working alongside others to working with others — maintaining trust, seeking support when needed, and creating the professional relational conditions for effective collaboration across roles and disciplines.

Interconnection subskills

- 3a. Identify potential growth opportunities arising from interpersonal connections in professional and learning contexts.
- 3b. Initiate, maintain, and respond to social interaction in ways that promote openness and build connections with a range of profiles.
- 3c. Constructively and proactively create opportunities for increased interaction with and between people to develop networks around you.

By distinguishing interconnection subskills, we make explicit how relationship-building moves from recognition to action: 3a) noticing why a connection could matter (for learning, support, opportunity, or inclusion); 3b) using interaction moves that build

trust and openness (e.g., expressing interest, following up, offering to help); and 3c) creating repeated opportunities for interaction that turns one-off contacts into durable networks. Example 3 illustrates how you can support students in developing interconnection subskills 3a-3c in an interdisciplinary, stakeholder-facing module design by acknowledging that building trust in teams requires engaging with moments of tension and discomfort rather than avoiding them. When students learn to stay in such moments and respond constructively, they develop the capacity to form deeper and more resilient professional relationships. Evaluated through student surveys, this approach strengthened communicative competence across diverse teams (Peters et al., 2024).

Example 3. Interpersonal and interconnection skills

As taught by I. Peters and S. Ammon in the Fair Mobility module, Berlin Ethics Lab, Technical University of Berlin.

Purpose

This module-level example shows how interconnection skills can be taught in interdisciplinary, stakeholder-facing projects.

How to facilitate the activity with students

- 1. Establish module structure: Form student teams for diversity in discipline, gender, and background. Introduce methods (e.g., stakeholder mapping) for students to identify relevant external partners themselves (e.g., city planners, NGOs). Facilitate co-development of one shared research question.*
- 2. Prepare students for emotional dynamics: Explain that interdisciplinary work may challenge assumptions and trigger emotions (frustration, uncertainty...), framing these as normal and signals of learning and relationship-building.*
- 3. Practise (embedded during activities): When unpleasant feelings arise during project work, remind students that such moments are not only normal but central to learning in interdisciplinary collaboration. Encourage students to recognise and work through these emotional responses, as this is key to developing meaningful professional relationships across disciplines. Use low-stakes check points with questions (What priorities shape your view? How does that connect to last week?) and repair moves, such as clarifying roles.*
- 4. Close + transfer: At the conclusion of each project phase, assign a 300-word reflection (Which of your own assumptions were challenged? How did you react emotionally? How did this affect your interaction with others? What changed in your perspective?) followed by a team debriefing.*

Why it works

- Makes the skills visible: Students are supported to perceive and leverage growth opportunities by actively seeking developing professional relationships with diverse partners.*
- Fosters growth culture: Normalizes emotions as success signals; students practice trust moves during worldview challenges.*

- *Fosters transfer: With repeated opportunities, discomfort is turned into networks, and relational labour is more visible.*

What this shows

You can support students to develop interconnection skills by (1) naming the interpersonal communication risk (working in parallel, exclusion from informal networks); (2) providing short scripts for initiating and maintaining connection (reach out, ask a genuine question, offer a concrete contribution, follow up); and (3) giving students repeated, real-task encounters followed by reflection that links one interaction cue (silence, hesitation, withdrawal, increased openness) to one trust building move (clarify expectations, invite input, acknowledge effort, propose another meeting).

A useful lens for developing interconnection skills is social identity: how people understand themselves and others in terms of group memberships, roles, and status. In engineering education, local values and norms can shape which kinds of relational behaviour are seen as legitimate. In many settings, norms associated with independence, competition, and emotional restraint can make relational work seem optional or non-technical (Secules, 2019). These norms can also create asymmetries: the same level of disengagement may be interpreted differently depending on who enacts it, potentially reinforcing exclusion (Cannaerts et al., 2025). Making interconnection teachable helps students see relationship-building as part of professional competence rather than as personality or extra labour.

In settings where networking and relationship-building are assumed rather than taught, some students may not recognise their value (3a) or may rely on narrow, familiar circles, leaving useful contacts invisible. Even when students recognise the value of networking, they may lack concrete interaction strategies (3b) or feel that reaching out signals weakness — especially where self-sufficiency is rewarded. In addition, some students face structural barriers to informal networks and mentorship, which can reduce access to opportunities and support (Krivoshchekov et al., 2025).

Where students are given explicit strategies and low-stakes practice, interconnection becomes more deliberate: they initiate contact, follow up, and use small relational moves (e.g., appreciation, clarification, help-seeking with specificity) to build trust. At this stage, students also begin to notice who is doing relational maintenance and whether that labour is distributed fairly. Research suggests that the relational and emotional labour that supports group cohesion can fall disproportionately on marginalised students and may remain undervalued (Kimpton & Maynard, 2025). Making this labour visible (and assessable when appropriate) helps avoid treating inclusion and cohesion as ‘free’ outputs of group work.

Expert interconnection involves sustaining diverse networks while enabling others to connect and collaborate. Rather than treating relationships as transactional, interconnection experts create conditions where trust can be repaired after friction and where support-seeking is normalised. This level of competence often requires

openness, empathy, and a capacity to tolerate uncertainty — qualities that conflict with dominant norms in some engineering contexts (Krivoshchekov et al., 2025). When students model counter-normative practices (e.g., naming uncertainty, explicitly valuing mutual support), they help shift local cultures so that relational awareness and proactive connection are recognised as professional engineering competence.

4 Recommendations for implementation

Despite the intentions of engineering educators, students' development of interpersonal skills is often delayed by a lack of explicit instruction on and scaffolding of these skills (Isaac & de Lima, 2024). This may result in students perceiving interpersonal challenges exclusively as impediments to completing their tasks and not as learning opportunities to develop key skills.

The activities described in this section can be used as plug-in routines to introduce interpersonal communication skill development into your teaching. Identify a relevant sub-skill, then run a 10-20 minute cycle: (1) name the subskill and the interpersonal communication strategies for implementation; (2) students engage in an application activity; (3) students use a checklist or rubric to give each other one 'keep doing' and one 'try next time' feedback comment; (4) wrap up by asking students to consider what cues they noticed and what they will do next time. These steps follow the 3T PLAY framework of experiential learning by providing students with conceptual or practical knowledge to underpin the skill, followed by a low-stakes opportunity to practice their developing skills, and a conclusion that supports their ability to apply their skills in their engineering coursework. Repeat the cycle across the semester in labs, design work, or project activities to allow students to develop robust skills.

Tables 2.10.1, 2.10.2, and 2.10.3 provide exercises you can use to integrate listening, adaptive communication, and interconnection skills into existing engineering modules (labs, design reviews, teamwork, check-ins). For example, the 3T PLAY trident framework can be used to structure listening activities — give students a simple conceptual model (e.g., 'content vs emotional affect' or 'paraphrase and check'), run a short pair listening exercise, then close with a reflection on the cues they noticed and how they responded. For adaptive communication, prompt students to surface assumptions (e.g., what is taken for granted?) and practice one language move (e.g., define a term, reduce jargon, check interpretation). For interconnection, use team projects and industry or community collaborations to make relationship-building visible as part of coordination, so students can see how successful coordination depends on trust, follow-up, and timely help-seeking.

Even a small dose of structured interpersonal skill practice can improve coordination and decision making in sociotechnical work, especially when students must collaborate across disciplines and with stakeholders to anticipate impacts and prevent harm.

Table 2.10.1: Practice activities for developing listening skills

<i>Skill</i>	<i>Practice activity</i>	<i>Activity description</i>
Distinguish emotional and cognitive components	Dual-level listening (Rogers & Farson, 1957)	Learners listen to the same message twice, paying attention to: - cognitive components, focusing on facts and arguments by asking "what is being said?" - emotional components, observing tone of voice, word choice, and body language by asking "how is it being said?"
Identify emotional states	Reflecting feelings (Hargie, 2021)	Learners formulate the feelings they perceive from their conversation partner and reflect them back to verify their impressions
Identify potential implications	Conversation strategies guided by emotions (Egan, 1969)	Learners match emotions to Egan's conversation strategies for emotional states by acknowledging feelings explicitly and responding appropriately: - anger > de-escalate - insecurity > proceed step by step - disappointment > listen empathically - enthusiasm > use positive energy
Respond coherently to another person's messages	Paraphrasing and reflecting (Gordon, 2003)	Learners verbalise the factual content they have heard and the emotions they have perceived, using their own words and incorporating appropriate conversation strategies
Employ active listening strategies	Signalling active listening (Hoppe, 2006)	Learners show their conversation partner that they are actively listening by sending verbal and non-verbal listening signals, including paraphrasing, eye contact, and gestures of agreement

Table 2.10.2: Practice activities for developing adaptive communication skills

<i>Skill</i>	<i>Practice activity</i>	<i>Activity description</i>
Acknowledge the incompleteness of knowledge sets	Critical friends (Costa & Kallick, 1993)	Learners give a presentation on a problem from their disciplinary perspective. An ideally interdisciplinary audience asks critical questions from their own disciplinary perspectives, using orientation questions such as: • What seems taken for granted? • What perspectives are missing? • What alternative explanations exist? Presenters reflect on the situatedness and limitations of their disciplinary perspective
Recognize norms and biases	Discourse markers analysis (Maschler, 2008)	Learners analyse a communication (e.g. peer presentation) to identify terms that are value-laden, normative or based on specific assumptions. Examples include: • interpersonal markers: look, believe me, you know... • cognitive/epistemic markers: should, must, I think, probably ...
Adapt language and communication style	Interdisciplinary science communication (Noviello, 2021)	Learners generate a list of good practices for effective interdisciplinary communication, such as avoiding acronyms and explaining figures (Noviello, 2021)
Integrate different knowledge sets	Group concept map (Kane & Trochim, 2007)	Learners generate a shared question to guide them in collecting their ideas and perspectives on the topic in the form of keywords and sort these into clusters. The team then creates and interprets a concept map to reach a shared understanding of the research topic

Table 2.10.3: Practice activities for developing interconnection skills

<i>Skill</i>	<i>Practice activity</i>	<i>Activity description</i>
Identify potential growth opportunities	Stakeholder analysis (Berardo & Murphy, 2023)	Learners map their contacts by: - defining stakeholders in the context of a specific issue - identifying relevant stakeholders (e.g., individuals, groups, organizations) - analysing relationships, positions, and potential conflicts or opportunities for cooperation
Promote openness and build connections	Speed networking (Cross et al., 2010)	Learners practise conversation starters and small talk tailored to their own networking needs in short sequences (3-5 minutes) with rapidly changing conversation partners, based on a given objective
Create opportunities for increased interaction to develop networks	Action plan development (Ferrazzi & Raz, 2005)	Learners draw up an action plan for establishing and expanding their professional network. Examples include: - identifying desired contacts and opportunities to generate interaction - their own potential to support others

To allow your students to fully benefit from these activities, design the interaction environment deliberately. Set discussion rules early in the module (e.g., respectful listening that allows others finish their thoughts, ask one clarifying question before you disagree) and refer back to the rules during project work. Reduce status barriers where you can by modelling behaviours that reduce hierarchy (*"I do not know that myself — yet"*) and treating questions and mistakes as normal parts of engineering judgement, not as failure. Build perspective diversity into course work (e.g., heterogeneous groups, rotating roles, input from external stakeholders) and make it explicit that different priorities are a resource for responsible decisions. Prepare students for irritation and uncertainty by framing them as diagnostic signals that perspectives differ, then give them simple repair language to use in the moment (e.g., *"Can we define that term?"*, *"What assumptions are we making?"*, *"Let me check I understood you"*). Where possible, reduce hierarchies during discussions by inviting quieter voices first and separating idea evaluation from status (test the claim, not the person).

This chapter described three interpersonal communication skills for engineering students — listening, adaptive communication, and interconnection — and proposed

how to teach them through structured practice, feedback, and reflection. We used social dimensions (emotions, perspectives, and identities) as lenses to explain how these skills shape what we notice, how we interpret it and what we feel able to say or do, and therefore why these skills may break down in professional interactions. We have provided example activities for scaffolding the development of these skills in engineering teaching, supporting students' interpersonal communication skills essential for engineering practice: coordinating within teams, collaborating across disciplines and with stakeholders, handling disagreement constructively, and working with the uncertainty and risk inherent to professional engineering practice.

Finally, in addition to the literature referenced in this chapter, in particular Krivoshekov et al. (2025) and Isaac & de Lima (2024), we would also like to recommend the work of Khoo et al. (2018) on epistemological differences if you want to further deepen your knowledge.

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AI statement

During the preparation of this work the authors did not use any AI tools.

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2.11

Feedback for Learning in the Engineering Disciplines

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Keywords: *assessment, diversity, formative feedback, summative feedback*

Effective feedback is a fundamental part of any educational process, enabling reflection, action, and future improvements to be made by the learner. Feedback-literate students are able to recognise different forms of feedback, manage their feelings and emotions when receiving feedback, capable of acting upon feedback, and able to make evaluative judgements on the quality of their own work and that of others. In university settings, assessment and feedback are often presented together; the importance of combining learning, assessment, and feedback in integrated curriculum design is discussed. Guidance for what makes effective feedback is presented for educators grounded in student-centred models of feedback which go beyond task-level comments and grades. Feedback is a learning dialogue where diverse student populations need clear and appropriate feedback to achieve their potential. Having established the features of good feedback, these are expanded into methods to develop feedback skills in students, with specific example interventions highlighted in a manner which supports educators to implement them in their own curriculum.

1 Definition

1.1 Concept

We define feedback as “*a process through which learners make sense of information from various sources and use it to enhance their work or learning strategies*” (Carless & Boud, 2018). This definition centres learners; any feedback strategy should be a student-centred, active process to scaffold learning. Feedback is active working alongside knowledge and understanding, which allows students to connect, redefine, and develop skills, and build further knowledge.

Feedback can be split into two sub-skills: receiving feedback and giving feedback.

- Receiving feedback: “*the understandings, capacities and dispositions needed to make sense of feedback information and use it to enhance work or learning strategies*” (Carless & Boud, 2018, p. 1316).
- Giving feedback: “*the ability to give constructive feedback to improve team members’ performance*” (Leandro Cruz & Saunders-Smiths, 2019, p. 13).

The timing and purpose of feedback within education results in further definitions which are sometimes understood differently. We define the following sub-types of feedback:

- *Formative feedback*. Feedback where the primary function is providing information “*intended to modify ... thinking or behaviour for the purpose of improving learning*” (Shute, 2008). This type of feedback should correct misconceptions and enable learners to plan future actions. Assignments and tasks providing formative feedback are *assessment for learning*. These may contribute to a student’s mark, but care should be taken with providing grades as some studies find that this reduces the effectiveness of feedback for students (Black & Wiliam, 1998; Lipnevich & Smith, 2009; Morris et al., 2021).
- *Summative feedback*. often defined in opposition to formative feedback, this can be attached to an end of unit assessment or high-stakes assignment where feedback is not designed as part of a learning sequence, so it is more challenging for learners to apply to their future development. The primary purpose of summative assessment is benchmarking students against learning objectives and competencies at the time of the test, rather than providing feedback (Ahmed et al., 2019; Harlen, 2005; Ishaq et al., 2020). This is *assessment of learning*.

1.2 Key feedback frameworks

We have selected two frameworks for presentation from the literature which we consider most accessible for engineering education. Both address what makes effective feedback, and mechanisms to provide and act upon it. Students are placed at the centre of feedback processes, acknowledging that feedback demands cognitive and emotional work from students.

The Hattie & Timperley Model

Hattie and Timperley (2007) highlight properties of impactful feedback (Fig. 2.11.1). They identify the purpose of feedback in reducing gaps between current and desired understanding, framing feedback as an active part of the learning process. The three questions posed help students understand their current level, what to do next, and what the goals are. The model is supported by a meta-analysis from Wisniewski et al. (2020), who argue that the most effective feedback provides students with information on their errors, but also an understanding of why these were made and how they can be avoided in future.

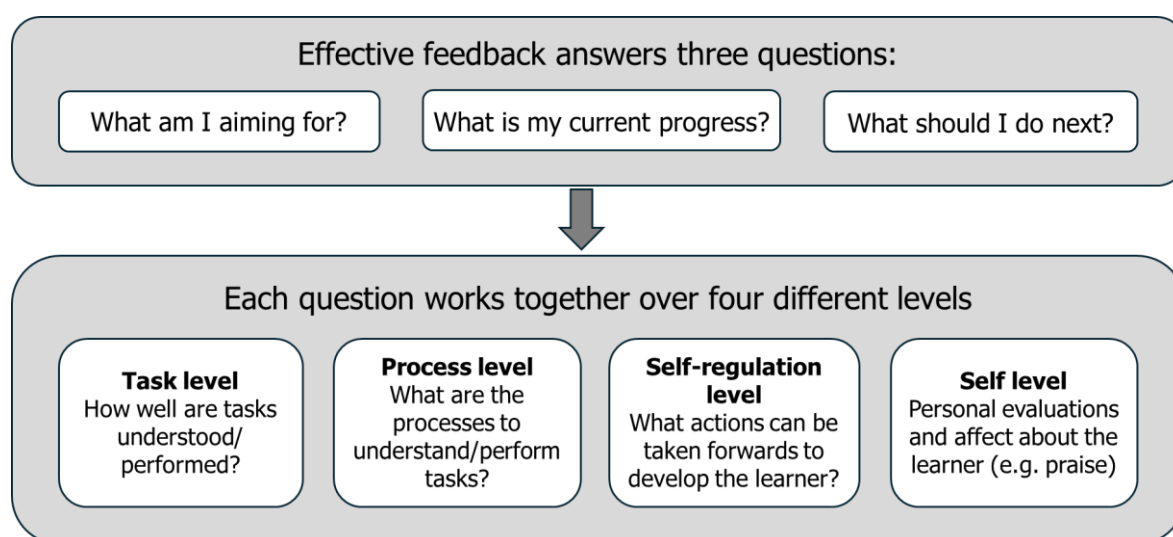


Figure 2.11.1: Effective feedback in the Hattie & Timperley model of feedback.
Adapted from Hattie & Timperley (2007). Copyright SAGE.

The Integrative Model of Feedback Elements (MISCA) Model

The Integrative Model of Feedback Elements (MISCA) (Panadero & Lipnevich, 2022) takes fourteen models, discussed in more detail in Lipnevich and Panadero (2021), combining these into a single model. MISCA stands for Message, Implementation, Student, Context, and Agents, as highlighted in Fig. 2.11.2. The design centres students and their interaction with each aspect.

- *Students.* Students are individuals so respond to feedback differently. This includes prior knowledge, personality traits, and cultural differences amongst others.
- *Message.* The content of feedback should allow students to understand where they made mistakes, why they made them, and how to avoid these in future.
- *Implementation.* The purpose of feedback is to enable students to improve their skills and understanding, not only how to improve on a specific task. When feedback is provided, this requires students to manage their emotions and feelings too.

- *Context.* Feedback must be provided in a setting where it can be acted upon and in an environment which supports learning from feedback. Context also includes the recognition of the variability of feedback practices between disciplines and institutions.
- *Agents.* Feedback can be given by educators, but also via peer and self-assessment. Interactions between the feedback provider and the feedback receiver impacts the effectiveness.

A crucial contribution of the MISCA model is in acknowledging complex interactions between elements and the importance of their alignment.

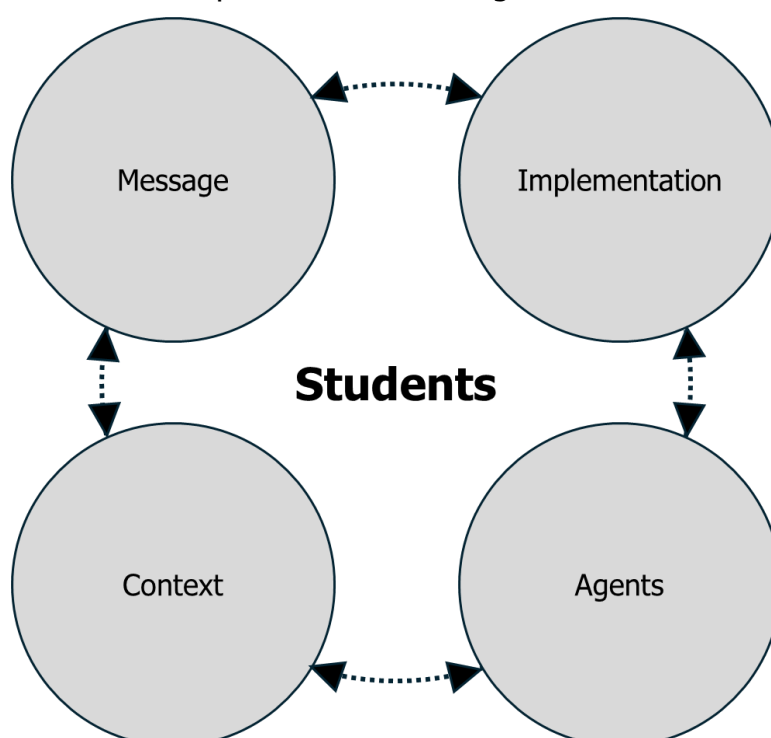


Figure 2.11.2: Simplified version of the MISCA model. Own Work, adapted from Panadero & Lipnevich (2022)

1.3 Feedback as a student-centred process

Both models centre students in feedback processes, moving from historic views that feedback is provided by educators and received by students, to a view that sees learners as active participants. Students need to develop *feedback literacy* to become these active learners. The provision of effective feedback supports students in their development.

For a more detailed discussion of feedback literacy, see Chapter 2.12, Building Feedback Literacy: Essential Skills for Engineering Education and Professional Practice.

Assessment design should incorporate feedback design. This leads to overlap between *feedback literacy* and *assessment literacy*; both are key to supporting learning.

Elkington and Evans (2017) discuss that students require the following knowledge for assessment literacy:

- Appreciation of the relationship between assessment and learning;
- Conceptual and theoretical understanding of assessment;
- Understanding of the nature and meaning of assessment criteria and standards;
- Skills in self- and peer-assessment;
- Familiarity with assessment techniques.

1.4 Positive feedback

Feedback should be focused on the process of, or engagement with, improving understanding (Hattie & Timperley, 2007). Hattie and Timperley argue that feedback at the 'self level' is the least effective. However, by providing positive feedback about the self which can be acted upon (rather than praise), it can be made more effective. Positive feedback where students are congratulated on their work and highlighting success can be part of effective feedback. Positive feedback is effective when it helps learners develop self-regulation (Wisniewski et al., 2020), thus acting within the implementation domain of the MISCA model.

2 Why teach feedback skills?

2.1 Importance for engineers and engineering education

In engineering control systems, we understand the importance of feedback with closed loops which allow past states to impact behaviour in the present. Feedback in an educational sense is as critical to engineering students and professionals; we see it as how and essential way for students to learn, self-correct, and improve future performance.

Feedback within engineering programmes

In Carless and Boud's (2018) definition of feedback, the aim is to "*enhance work and learning strategies*", highlighting the value of *future-proof* feedback; it is transferable to other contexts and other assignments, so that mistakes can be avoided in future (Hattie & Timperley, 2007; Wisniewski et al., 2020).

Within engineering, there are objectively right and wrong technical answers due to the nature of the discipline. Effective feedback should, however, allow clarification of *why* mistakes are made, so these can be avoided in future.

Many engineering accreditation processes implicitly require students to receive and provide feedback within communication and interpersonal skills (for example criterion 3: Student Outcomes within the ABET framework). Both receiving and giving feedback are competencies which draw upon a range of other transferable skills; interpersonal communication skills (see Chapter 2.10); adaptability (see Chapter 2.14); and resilience (see Chapter 2.15). This is because when receiving feedback on skills and understanding, learners must still manage their emotions and feelings (Panadero & Lipnevich, 2022).

Feedback as an engineering management skill

Professional engineers often have significant management roles and are responsible for providing feedback to their teams. Developing feedback literacy in students prepares them for this role through experience of receiving and giving feedback during their studies. Commitment to lifelong learning is part of professional standards (ENAAE, 2021). The self-regulation skills (see Chapter 2.13) and self-evaluation skills developed within feedback literacy (see Chapter 2.12) support lifelong learning, enabling individuals to identify areas for personal development.

2.2 The power of peer feedback

Peer feedback is “*a communication process through which learners enter into dialogues related to performance and standards*” (Liu & Carless, 2006, p. 280). This dialogue provides skill development in feedback literacy; students are required to be active participants, providing opportunities to judge the work of others, allowing for development of self-assessment skills.

Some students prioritise feedback from educators (Coppens et al., 2023), while others find peer feedback more useful (Søndergaard & Thomas, 2004). Selwyn et al. (2025) recommend highlighting the benefit to learning in providing peer feedback — this can help address student perceptions that peer feedback is of lower quality than educator feedback (Hamer et al., 2015). Peer feedback can be a powerful tool, however, in recognition of the diversity of students and curricula; it is one method within a larger toolbox.

Peer assessment is when “*individuals consider the amount, level, value, worth, quality, or success of the products or outcomes of learning of peers of similar status*” (Topping, 1998, p.250). This can provide assessment of disciplinary content and transferable skills. In engineering, peer assessment can be used during group work to distinguish contributions from individuals (Fry et al., 2002). This provides opportunities for students to give and receive feedback on their transferable skills (teamworking, communication etc.). We suggest that this is most effective when feedback is used formatively, supporting the group to function and correct their course during a module — rather than as summative peer assessment; allocating marks after assessments are complete.

3 Forms of implementation

Educators spend much time providing feedback; it therefore important to focus on design and methods which enable students to act upon feedback. Educators need to provide learning environments that motivate learners to acquire, use, and demonstrate competences within real-life contexts (CAST, 2024). Within active learning environments, learners both receive and provide feedback, allowing development of these skills.

3.1 Programme level

Based on the arguments provided in this chapter, feedback is inseparable from assessment and is an important part of making assessments valuable for the learner

(CAST, 2024). Designing feedback into any curriculum unit should aim to close the feedback loop, allowing learners to progress and improve.

Programme level planning should ensure students' learning experience builds throughout the programme, with assessment methods aligned to learning activities and outcomes. In a coherent programmatic approach to assessment, all elements of assessment and feedback are strategically related with purposeful intent to achieve programme learning outcomes. Students are provided with information on their learning outcomes and how assessment is designed for them to use feedback. We therefore recommend:

- Ensure students understand how assessment works and what level they should evidence in work. Students need to understand what marks represent and how to interpret feedback comments;
- Test understanding and skills in formative tasks. Provide guidance on how feedback can be used to improve;
- Demonstrate linkage between formative and summative assessments, making clear the purpose of using different types;
- Plan the student journey, weaving formative and summative assessments with feedback both within, across and outside modules;
- Ensure the development of feedback literacy skills, rather than providing feedback alone.

At programme level, feedback should be embedded in assessment design and considered as *process*, not product (Carless, 2016). In this way, programme-level assessment includes consideration of programmatic feedback. These approaches help in deciding how and when students will create or receive feedback.

From our practical experience, a feedback strategy for programmes should consider:

- The number of opportunities where students receive formative and summative feedback;
- When feedback is available and feedback activities are undertaken;
- How students create, receive, and use feedback. What support mechanisms are available to ensure students can close the feedback loop?

3.2 Module level

At a modular level, based on our practical experience, you should consider:

- The assessment type that best fits with module learning outcomes, and in turn how this matches the programme approach to assessment already developed;
- The combination of approaches to assessment, ensuring programmes do not repeatedly assess the same learning outcomes and preventing assessment bunching;
- Allowing space for formative assessments and the feedback arising from these to be incorporated into student preparation for summative tasks.

Within the module, explore and develop exercises and initiatives that are designed to improve student assessment and feedback literacy; make sure to communicate

academic standards to students. Consider how feedback will be generated, disseminated, and utilised by students.

Example 1. Academic feedback process

All students will be provided with information at the start of the academic year about the feedback they will receive. This will set out what, when, and how students will receive feedback, in summative assessments and on an ongoing basis, e.g. through tutorials, from supervisors, on formative assessments etc.

What?

As a minimum, it is recommended that students be provided for each assessment task:

- *The name and a brief description of the assessment;*
- *Percentage contribution of the task to the module's outcome;*
- *Format(s) for the submission of the assessment;*
- *Whether it is a summative and/or formative task and the pass mark;*
- *Duration of the assessment and/or its length/volume;*
- *Assessment criteria;*
- *Assessment release and deadline dates;*
- *Deadline for return of feedback comments;*
- *What feedback follow-up opportunities exist.*

It is also good practice to follow up through in-class discussion. Talking with students about feedback presents an opportunity to make students more aware of the benefits and responsibilities they have to utilise feedback to improve their learning.

Provide information on the format of feedback, any differences between feedback given on formative and summative assessments, and any opportunities for additional feedback.

When?

Information about feedback should be provided to students at the start of each year.

How?

Make clear to students where information about feedback can be found, and whether additional supports are available.

3.3 Engaging with feedback and assessment

Section 1.2 introduced two models for feedback. Here we present some forms of implementation from practical experience, where assessment is designed by educators to facilitate engagement with feedback and assessment.

Example 2. Interventions to improve feedback engagement

Recognise and appreciate feedback:

- *Give an example of previous feedback, explaining or identifying how students could use this feedback, and discussing their responses;*
- *Students outline examples of feedback they have already received;*
- *Students present their own definitions of feedback, then discuss and deconstruct their responses to help with understanding (e.g. marks are not feedback; that comments only become feedback when they are acted upon).*

Managing affect (emotional impact):

- *Students discuss in pairs the feedback they have received. Ask each pair to discuss how did negative comments make them feel. How can negative comments be reframed and used to improve? Why it is important for feedback to include negative comments?*
- *Signpost students to information, support, and advice, should you feel that feedback poses well-being risks;*
- *Ensure feedback comments balance constructive criticism, positive comments, and directions to improve;*
- *Give students permission to fail, by ensuring initial developmental tasks carry little (if any) weight to module marks.*

Taking action:

- *Include links to useful resources in feedback, directing students to utilise these;*
- *Ensure feedback is acted upon, e.g., by asking students to set out how they have used previous feedback on the coversheet of their next assignment, or by awarding marks for explaining how they have used previous feedback;*
- *Allow students to get and implement feedback on drafts prior to the final assignment submission.*

Making evaluative judgements:

- *Provide exemplars alongside assessment criteria. Ask students in small groups to grade the exemplars, applying the assessment criteria. Then discuss different marks and responses, thus making students more aware of the complexity involved in grading and providing feedback;*
- *Ask students to self-assess their own work, submitting a cover sheet that includes their own predicted mark based on the criteria. Then provide students with feedback that comments on their marking, helping to hone their evaluative judgement;*
- *Ask students to work with a peer assessment prior to submission, providing feedback on work in progress against grading criteria;*
- *Help students to better understand assessment criteria by using generic criteria to then develop assignment-specific criteria. Then ask students to work in groups, discussing the meaning of criteria and articulating the features of work at each level.*

3.4 Codesigning assessment and feedback

Agreeing an approach to feedback with your students can have positive impact. For example, introducing formative assessments that are awarded an indicative mark and clearly linked to summative assessment performance, can reduce marking workload. It can also allow the assessment focus to be placed on the feedback. Furthermore, students can be involved in peer feedback. Time spent providing this feedback is more valuable to students than comments at the end of a module that are unlikely to be used elsewhere.

Example 3. Collaborating on assessment criteria

Involving students in assessment criteria design improves feedback literacy. This could include discussions where you collaboratively:

- *Adapt existing criteria;*
- *Review alignment of assessment criteria with learning outcomes;*
- *Discuss what educators look for in assignments;*
- *Share and discuss different types of criteria that can be applied to different tasks.*

Staff can also support the development of feedback skills by demonstrating their own feedback literacy as part of standard university processes. Universities typically request from and provide feedback to students outside of assessments (e.g., module questionnaires, learning community forums, student representatives). Explicitly labelling this feedback alongside educators, demonstrating feedback literacy by engaging with these processes and acting as role models, provides clarity and guidance to students.

3.5 Project supervision

Individual projects are central to many engineering programmes and provide opportunity to implement personalised formative feedback dialogues using a range of methods. Signposting feedback mechanisms within projects at the start can help build feedback awareness, enabling students to take greater ownership of project work alongside developing professional skills. Due to the highly specialised nature of projects within different disciplines and challenges of assessing such work, the fundamentals of good feedback should form part of assessment design processes.

3.6 Self- and peer feedback

While some students may not initially be keen on self- or peer assessment, either finding it uncomfortable to participate in, or believing that assessment should come from educators. However, there is extensive research showing that skills development through these exercises is valuable to future assignments and to practicing engineers.

Self- and peer assessment can provide timely and effective feedback in larger classes but providing adequate time and training for students is an important design consideration (Henderikx et al., 2025).

Supporting students to develop their evaluative judgement enables them to self-assess their work, generating highly personalised feedback. A useful resource for helping students develop this skill is Nicol (2022)'s Active Feedback Toolkit. The process of generating inner feedback begins when students first complete a task, then compare it with an external resource, and then make explicit outputs of those comparisons. You can utilise reflective feedback coversheets or give students the chance to ask for feedback on a specific area when assignments are submitted. These help in generating dialogue in assessment feedback (Bloxham & Campell, 2010), while also demonstrating how students engage with feedback.

Peer feedback can be split into two delivery categories: synchronous and asynchronous, each with opportunities and challenges.

- Synchronous peer feedback can be used for discipline-specific work and evaluation of competencies (presentations, teamwork etc.). Synchronous methods are most beneficial when feedback value is given in dialogue between learners (Bartholomew et al., 2019), and which allows clarification and further discussion.
- Asynchronous peer feedback allows students to review others' work and compose feedback at their own pace (Jongsma et al., 2023). This format is suited to assignments where clear suggestions to improve work can be made (e.g. reports). Online tools can help coordination and allow for anonymisation. Anonymisation can produce more direct feedback in how to improve work but may need to be balanced with greater educator oversight to ensure that feedback is constructive.

Example 4. Examples of supporting self- and peer assessment

Require students to complete a self-assessment sheet with submitted assignments, structured around the criteria, so they are obliged to reflect upon their own work against assessment criteria before receiving feedback.

Use peer feedback forms for formative assessments, requiring students to give targeted feedback mapped to the assessment criteria. It may be useful for individual students to focus on one criterion each, such as content, structure, delivery, or visuals.

Consider encouraging students to use generative AI to create feedback on their own written assignments, providing them with guidance on effective prompts related to assessment criteria (however it is important to discuss with students how AI can make mistakes).

Run exercises in which students mark assignments and then discuss their critiques and marks with other students.

3.7 Written feedback

Written feedback (open-ended comments) is asynchronous feedback and should align with the best practice principles within this chapter. Written comments enable the

provision of detailed, personalised feedback, which is inherently flexible. Written feedback can be delivered quickly and efficiently, especially if using a common set of annotations for common feedback points for students on the same assignment, allowing students to engage at their own pace (McCarthy, 2015). When positioned directly alongside relevant sections of text, written comments create a clear and immediate link between feedback and students' work (Brookhart, 2017).

The limitations of written feedback are often due to its asynchronous nature. Additionally, written feedback lacks non-verbal cues present in synchronous feedback processes, so tone must be considered. Using encouraging and constructive language positioning students as active participants in learning is essential, while avoiding phrasing that could be perceived as overly critical or discouraging (Brookhart, 2017).

3.8 Rubrics

A rubric is an assessment tool outlining criteria and performance levels for a task. It has the potential to guide consistent, transparent grading by specifying expectations and standards. It can provide with greater confidence and reassurance that grading is objective, unbiased, and "*educationally more defensible*" (Sadler, 2009) because of this increased transparency. Rubrics can assist students with understanding how their work will be evaluated and support constructive feedback for improvement. Cockett and Jackson (2018) found that "*there are some advantages to be gained by using rubrics to enhance feedback to students*", but that they cannot be viewed as a panacea for all feedback-related issues.

A well-designed and well-implemented rubric can be a useful feedback tool for both teachers and students. From the educator's perspective, rubrics provide clear, measurable criteria which connect directly to learning outcomes. This gives a point of reference to measure the student's distance from a given learning outcome, thereby helping to shape feedback. From the perspective of the student, there is evidence rubrics can have a positive impact on student learning, as long as the design and application are aligned (Panadero & Jönsson, 2020).

The role of a rubric depends on whether it aims to provide formative or summative feedback. Much of the original research on rubrics focused on the latter. However, recent research highlights formative usage of rubrics becoming more prevalent, which can improve performance in several ways, including incorporating feedback processes (Panadero & Jönsson, 2013). Academic consensus supports the use of rubrics (Rust et al., 2003, 2005) within a community of practice, but with the caveat that they should be one of many feedback methods. Due to the diversity of engineering disciplines, settings, and tasks, there is no single ideal text for their design, although Stevens (2023) and Brookhart (2013) provide useful guidance.

For a fuller account of rubrics, see Chapter 3.4 Rubrics: Design, Development and Implementation.

3.9 Audio and video feedback

Recorded audio and video feedback (where educators record their feedback messages) overcomes limitations of written or verbal feedback, providing a comprehensive and personalised learning experience which can be repeatedly reviewed (Bahula & Kay, 2021; Máñez et al., 2025). Through integration of visual and verbal cues, video offers rich and nuanced feedback, resulting in enhanced clarity and increased engagement (Davies, 2023).

Delivery methods may include recordings, use of specific software or in-person meetings (ideally allowing recording of verbal feedback to support diverse learners). Video feedback can also support cohort-level feedback, providing summaries, recorded screen shares, or physical demonstrations.

Example 5. Case study using video feedback at Cardiff University (Davies, 2023)

To tackle the challenge of students not engaging with feedback, thus overlooking an important part of their learning, alternative feedback mechanisms were explored over five years on a final-year structural engineering problem-based design module (approximately 140 students).

Ideally, one-to-one feedback sessions provide an authentic learning experience, but limited educator resources and time constraints made this unviable. The evaluation of video feedback shows students can be provided with personalised, authentic, and effective feedback, mimicking real-world design contexts. In this instance, 3-to-5-minute recorded video feedback was provided for each student submission.

Student comments were wholly positive, commenting on how engaging and pertinent feedback was in short video format. Over 90% engaged, compared to typically 45% engaging with previous written feedback. Student survey scores for the module incorporating video feedback improved over the period, increasing from 74% to 97% satisfaction. Students particularly valued the comprehensive reasoning provided and guidance on how to improve.

Whereas students may have previously challenged their marks, videos provided comprehensive reasoning and advice on how to improve in future. Over time, educator feedback evolved from simply talking to students into asking for responses and further thoughts on their work. This promoted two-way dialogue, helping close the feedback loop. Feedback morphed into emphasizing effort and practice rather than inherent ability as important, essential when designing inclusive learning.

The following advice should be kept in mind for creating effective video feedback:

- *Keep videos short and pertinent, between 3-5 minutes;*
- *Plan videos as if you were explaining feedback in person;*
- *Highlight and clarify feedback comments on the assessment, ensuring understanding;*
- *Provide simple and clear feedback, explaining ways to improve in future.*

4 Recommendations for implementation and learning

Feedback is important for student learning, but the combination of feedback with grades or marks can impede the effectiveness of feedback (Lipnevich & Smith, 2009; Winstone & Boud, 2020). Disentangling marks and feedback may not always be possible, but providing feedback may be one of the most important ways to improve learning.

4.1 Feedback for learning

Assessment for learning principles (Winstone & Boud, 2020) highlight feedback through formative assessment as an effective way to disentangle assessment and feedback, focusing on learning and improvement, rather than marks. Feedback after a submission is too late for students to make changes and is viewed by students as mostly unrelated to future development. Providing opportunities for students to practice an assessment and to receive formal or informal formative feedback before summative evaluation. This has been shown to be an effective strategy to improve performance through identifying deficiencies in understanding and how to rectify these. Formative feedback does not need to involve a full draft of the final submission but could focus on sections or key questions to benefit student learning, while managing educator workload.

Therefore, we recommend that educators should check with students whether they understand what is expected of them in assessments, how to evidence their learning, and, through co-creation, map and highlight feedback opportunities throughout their studies. Feedback to students should support learning and not only justify grades.

It can be helpful to read through feedback you have provided on an assessment, considering it from the student perspective. How would this feedback make you feel? Would you have a clear idea of the action you could take to improve your work in future assessments? When feedback is asynchronous, does it still provide interaction for the student, or is it a supportive narrative accompanying a mark?

Working with assessment criteria

In our experience, many students report finding assessment criteria unclear and the application confusing or inconsistent. Where students are introduced to criteria as broad guidance, rather than a detailed marking scheme, they are more likely to be satisfied with their use.

Therefore, it is important to clarify the pass mark for assignments and what it represents; is an assignment pass or fail with no other grade, or is the pass mark a threshold to be achieved or exceeded? This is particularly helpful for students coming from different educational systems and studying at different levels, where pass marks for first cycle (bachelor) or second cycle (master) degrees may differ. Students who enter university may be used to achieving high marks in secondary education, and the transition to higher education can produce challenges when they suddenly do not do very well. Therefore, you should provide students with support to manage the feedback they receive.

Providing structured class time can support students to develop self- and peer feedback skills. Asking students to apply assessment criteria to exemplars assists them internalising how to achieve them in their own work.

Example 6. Applying assessment criteria to exemplars

- *Provide students with a short piece of work (e.g. abstract from a draft paper, section of a report, elements from a proposal).*
- *Ask them to discuss applying the assessment criteria to the work and agree a mark.*
- *Groups share their marks with explanations.*
- *Groups review their awarded mark, applying learning from the group discussions.*

Enhancing feedback through closing the loop

Ensure feedback on formative submissions specifies criteria for improvement and ensures that students are given opportunities to clarify how feedback can be actioned.

Example 7. A two-stage assignment

Introduce a two-stage assignment, where the first formative submission is given an indicative mark only, with feedback that illustrates specific criteria for improvement. This helps students to better understand the criteria and provides an opportunity to immediately use the feedback to improve their work for the second submission.

To help manage workloads, discuss with students in advance that feedback will be provided on the first submission only, and that the final submission should comment on the ways feedback been acted upon.

4.2 Individual feedback

Wiggins (2012) provides an accessible model detailing seven hallmarks of effective feedback, providing a template for structuring feedback.

Goal-orientated. Feedback comments have more impact when related to both the learning outcomes and assessment criteria for the task. Provide a short feedback summary that identifies key areas for improvement and resources to achieve this, rather than providing feedback only on specific sections, or annotated text comments.

Focused on key points. Keep feedback concise and focused on two or three points, covering areas of strength and growth, as well as areas to improve. Concise feedback is easier for students to understand and is more likely to be acted upon.

Actionable. In addition to signposting resources for students to follow up on within feedback comments, discuss more broadly how students should action and utilise feedback. Where assessments are designed to support and build on each other, use feedback to signal what you want to see next time.

Student-friendly. Provide comments using first- or second-person language to help students engage. Content should be critical but constructive, where possible adopting an encouraging tone.

On-going. Feedback must be ongoing, consistent, and timely. This means students need opportunities to use feedback which is accurate and trustworthy. Build regular feedback loops into curriculum design. Where marking is completed by others, the management of the workload, deadlines, and consistency all need management. Encourage continuous discussions to develop feedback skills.

Consistent. Follow agreed standards, and provide trustworthy, fair, and accurate feedback.

Timely. Ensure agreed timelines are met, building trust and reliability in the feedback process. When feedback is not timely, students are disengaged and demotivated.

Group and cohort feedback

While some aspects of feedback skills development are highly individualised, group and cohort level feedback provides an efficient means of providing guidance and can be particularly helpful at the start of a module, allowing students to learn from previous groups. Cohort feedback can complement individual feedback, giving students awareness of common areas of weakness, and examples of successful performance. In large classes, cohort feedback can provide more timely feedback.

Example 8. Communicating cohort level feedback

Consider including information and a narrative on:

- *What did the highest-achieving students do well?*
- *What were the misunderstandings held by weaker students?*
- *Were there any common significant omissions?*
- *Were questions answered well? Were there specific questions that the cohort found challenging?*
- *How can this feedback be used by the cohort to improve their own work?*

4.3 Providing feedback to diverse cohorts

Meeting diverse needs of students and providing equity in assessment (Elkington & Evans, 2017) is crucial in a diverse higher education landscape. Ensuring all students can benefit from feedback requires consideration of the Universal Design for Learning Guidance (CAST, 2024), which is an international framework for inclusive education design which is widely used in the US, Ireland, and the UK. More details on this can be found in Chapter 3.7. Providing feedback using a range of methods is essential to ensure that multiple means of representation and engagement are explored, maximising the learning of all students.

Using multiple means of giving feedback involves provision of feedback in different modes, including written, audio, and video feedback. This could include a combination

of methods when giving feedback, such as feedback to a whole group, to an individual in person, or small groups exercising in interpreting feedback.

Students with diverse needs should be supported in developing feedback literacy, ensuring students can understand the importance of, respond to, and enact feedback from peers and others. Students from different backgrounds may not have received opportunities to develop an understanding of the applicable assessment and feedback processes, underlying values, and cultural norms. Curriculum design should include opportunities for all students to gain this understanding.

Offering a range of feedback methods is an inclusive act ensuring that students are not unfairly disadvantaged or advantaged by a specific format. All should follow the principles of effective feedback discussed in this chapter.

4.4 Using AI for creating feedback

Artificial intelligence (AI) can assist and improve the quality of feedback created for and by students within a more continuous assessment cycle learning environment. The models for providing feedback effective still apply and are technology agnostic. The Joint Information Systems Committee (2020) and Knight and Ferrell (2022) noted that thoughtful development and delivery of ethical AI practices can create autonomous learners by encouraging self-generated feedback and fostering self-regulation and reflection skills.

AI can enhance formative assessments by generating immediate feedback opportunities and mapping against learning outcomes. However, the variability of AI-generated feedback needs careful proctoring, to ensure alignment with pedagogic goals. Students and educators need to be guided on developing effective AI-generated feedback, through the iterative refinement of prompts and outputs.

With properly curated AI, feedback can become faster, personalised, and more meaningful for learning.

For a fuller account of AI practices, see Chapter 2.12: Building Feedback Literacy: Essential Skills for Engineering Education and Professional Practice.

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2.12

Cultivating Feedback Literacy in Engineering Education and Professional Practice

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Feedback literacy, critical for engineering, is the ability to effectively seek, interpret, use, and provide feedback across complex and diverse stakeholder environments. This chapter explores feedback literacy as a foundational skill that enhances engineering performance across technical and interpersonal domains, examining theoretical foundations and recent developments in feedback literacy theory. While frameworks to evaluate feedback literacy in engineering contexts are in active development, this chapter provides practical implementation strategies for developing these skills through authentic and experiential learning environments, engineering studios, and self-reflection methods. Additionally, we explore how innovations in generative artificial intelligence (AI) tools impact learners' and educators' ability to develop feedback literacy skills through improved feedback quality and personalised support. Through systematic curriculum integration that moves beyond simply delivering feedback to students towards approaches that empower students to seek, interpret, and act upon feedback, educators can prepare them for the lifelong learning and adaptability required in modern engineering careers.

1 Definition

Engineering practice demands more than technical expertise — it requires the ability to navigate complex design processes, iterate on solutions, and collaborate effectively across multidisciplinary teams (Le et al., 2010; Specht & Crowston, 2022). Engineers must continuously process inputs from multiple stakeholders to create solutions that meet complex, often conflicting requirements (De Weck et al., 2011). At the heart of developing these competencies lies feedback literacy, i.e., the ability to actively seek, critically interpret, selectively implement, and effectively provide feedback across diverse stakeholder contexts. While Chapter 2.11 establishes foundational principles of effective feedback, this chapter examines how to develop feedback literacy as a distinct professional competency.

1.1 Theoretical foundations: feedback literacy as active engagement

Feedback literacy emerged from a critical insight: not all feedback improves performance, because its effectiveness depends on how students engage with it (Hattie & Timperley, 2007; Kluger & DeNisi, 1996). As can be seen from the foundational frameworks discussed in Chapter 2.11, research now treats feedback as a dialogue between educators and learners rather than one-way information transfer. Feedback literacy builds on this idea, focusing on learners' ability to engage effectively in these feedback exchanges (Daumiller & Meyer, 2026; Hattie & Timperley, 2007; Panadero & Lipnevich, 2022; Winstone et al., 2017).

Sutton (2012) established a foundational definition of feedback literacy: understanding what feedback means and why it matters, recognizing one's agency in feedback processes, and knowing how to act on feedback. Modern frameworks build on this foundation. Carless and Boud's (2018) influential model identifies four interconnected components. *Appreciating feedback* involves understanding the purpose and value of feedback, while acknowledging the recipient's active role. This includes recognizing that feedback appears in various forms from diverse sources — peers, instructors, stakeholders, or self-assessment (Tenenbaum et al., 2020). *Making judgements* means developing the ability to critically evaluate both one's own and peers' work against established criteria through comparison and self-reflection (Nicol, 2021). *Managing affect* requires emotional regulation skills to maintain balance when receiving critical input, recognizing that feedback is inherently relational when provided by another human. Lastly, *taking action* involves acquiring strategies for translating insights into concrete improvements.

Molloy et al. (2020) then expanded this to seven groupings with 31 specific capabilities. These include:

1. *Committing to feedback as improvement* by embracing continuous development and viewing expertise as evolving rather than fixed;
2. *Appreciating feedback as an active process* that requires learner agency and understanding of standards;
3. *Finding information to improve learning* by actively seeking feedback from different people and sources;

4. *Acknowledging and working with emotions* by managing difficult feelings and building trust with those giving feedback;
5. *Acknowledging feedback as a reciprocal process* by recognizing dual roles as both provider and receiver of feedback;
6. *Processing feedback information* by making sense of what is said, comparing it to examples and standards, and thoughtfully deciding what to use;
7. *Enacting outcomes* through goal setting, planning, and monitoring progress.

This framework shows that students have more agency in feedback processes than previously recognized and provides a foundation for curriculum design and development of feedback literacy.

1.2 Engineering specific considerations

These frameworks are particularly important for engineers, who must regularly navigate feedback from diverse sources, translate input into technical improvements, and manage emotional challenges of critique in high-stakes contexts. For educators, this means feedback literacy instruction must go beyond teaching students to 'accept criticism gracefully'. It requires helping students develop sophisticated skills for managing competing inputs and making strategic decisions about implementation.

Moreover, feedback literacy varies significantly across disciplines. Recent scholarship recognises a plurality of feedback literacies, as practices are shaped by different learning environments, disciplinary specialisations, and professional demands (Gravett, 2022). Engineering feedback processes are shaped by disciplinary values and norms, pedagogical approaches, technical complexity, safety implications, and professional standards. For instance, feedback on a thermodynamics problem set, with clear solutions and single-source input, requires different processing strategies than feedback on a capstone design project involving multiple stakeholders, competing priorities, and regulatory considerations. Generic feedback literacy training will not prepare students for these varied contexts. Feedback literacy should be taught within the specific contexts where students will apply it, using authentic engineering scenarios that mirror the complexity they will face in practice.

Cultural and institutional contexts also influence how feedback is delivered, received, and implemented, as educational traditions, hierarchical structures, and professional communication norms vary across engineering programmes (Winstone et al., 2022). Engineering programmes are also shaped by accreditation and professional expectations that emphasise reflection, communication, and continual improvement. Making this link explicit helps students see feedback literacy as part of professional identity and lifelong professional development.

For you, as engineering educators, developing learners' feedback literacy means embedding it within authentic disciplinary practices rather than teaching it as a generic skill. This requires cultivating students' competency in two interconnected areas: feedback reception skills (i.e., actively seeking, interpreting, and selectively implementing guidance from diverse stakeholders) and feedback provision skills (i.e., evaluating technical work against professional standards and providing constructive

guidance to others). This dual focus is crucial because engineering students continuously exchange feedback through team projects, design reviews, and stakeholder interactions. Engaging with real engineering problems and experiencing the consequences of incorporating or ignoring input prepares them for the lifelong learning required in modern engineering careers. Developing these competencies requires integrating three domains: disciplinary expertise for technical evaluation, interpersonal competence for collaborative feedback exchange, and the ability to navigate technology-mediated feedback from digital tools and AI systems. Together, these create unique opportunities for developing feedback literacy, but each of these domains requires intentional pedagogical approaches (Fig. 2.12.1).

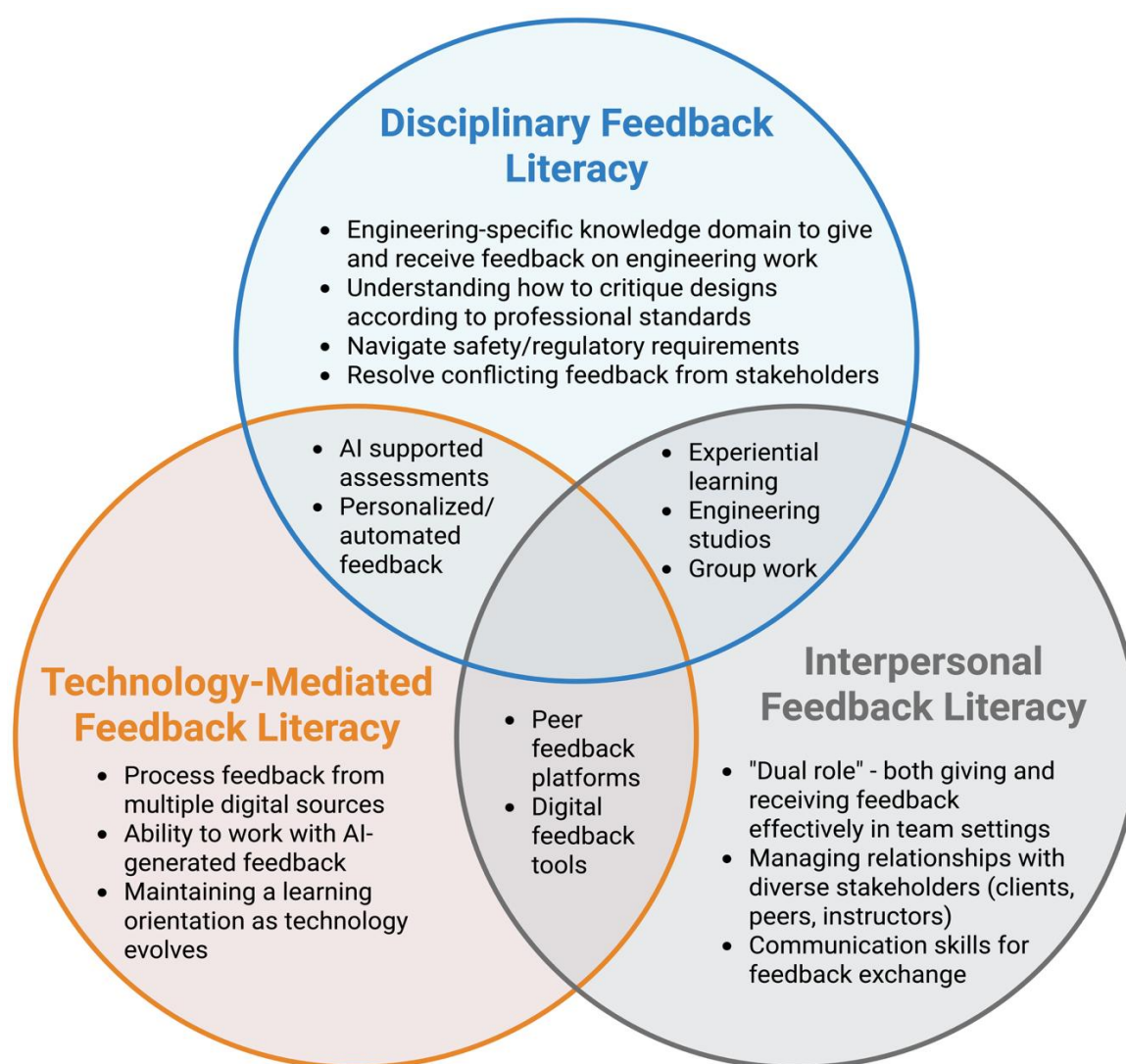


Figure 2.12.1: Engineering-specific feedback literacy framework. Feedback literacy in engineering requires integrating disciplinary expertise, interpersonal competence, and facility with AI-enhanced digital tools. Own work by Fuchs, Meyer, Butcher, and Werth (2026).

2 Why teach feedback literacy?

2.1 *Why feedback literacy matters for engineering practice*

Engineering is fundamentally iterative, requiring continuous refinement of solutions based on testing, analysis, and stakeholder input (Brunhaver et al., 2017). Engineers must process feedback from multiple sources to create solutions that meet complex, often conflicting requirements (De Weck et al., 2011). Engineers with strong feedback literacy can proactively solicit critiques on design proposals, interpret complex technical review comments accurately (Åström & Murray, 2021), apply insights to refine prototypes (Mohedas et al., 2020), offer constructive input to team members, and effectively manage the emotional responses often associated with critical evaluation (Nieminen & Carless, 2023).

In professional settings, feedback literacy shows up in design reviews, code reviews, safety audits, stakeholder conversations, and post-project retrospectives. Engineers who can ask for the right input, interpret conflicting perspectives, and turn comments into concrete revision plans can move faster and avoid repeat mistakes.

More importantly, developing feedback literacy becomes critical not only for improving engagement but also for enabling learners to be strategic and selective about implementation. This selectivity proves particularly vital in engineering contexts, where students must navigate feedback from multiple sources, including team members, instructors, industry partners, and increasingly, generative AI tools, while making informed decisions about which recommendations to prioritise and integrate. Without such preparation, students enter engineering practice lacking the sophisticated feedback literacy skills required for navigating complex stakeholder ecosystems.

2.2 *Why feedback literacy matters for engineering education*

For engineering students, feedback literacy encompasses dual roles as both feedback receivers and providers, making it a crucial catalyst for developing self-regulated learning and metacognitive skills needed for complex engineering problems and projects. Research reveals consistent gaps between perceived and actual feedback engagement in educational contexts: in settings focused on written assessment, students often fail to sufficiently engage with the feedback they receive (Meyer et al., 2025; Wang et al., 2020). This pattern extends beyond writing instruction. While design students reported that stakeholder interactions significantly shaped their design outcomes, analysis of their design reports revealed minimal actual incorporation of stakeholder feedback (Sugar, 2001). The gap between perceived and actual engagement highlights the need for explicit instruction in how to seek critical information from stakeholders and build constructive designer-stakeholder relationships (Dieter & Schmidt, 2012).

As feedback receivers, students must develop skills in analysing tasks, setting goals, planning activities, monitoring progress, and evaluating learning processes, which are core components of metacognitive development (Zimmerman, 2008). Simultaneously, their role as feedback providers proves equally valuable: research demonstrates that

training students to give feedback to others significantly improves both the quality of their future work and their capacity for self-regulated learning (Andrade, 2010; Donaldson et al., 2023).

This creates a reciprocal relationship where active engagement in both roles strengthens individual learning capabilities and professional competencies. When engineering students learn to objectively evaluate their peers' work against technical criteria, they simultaneously refine their own understanding of quality standards and develop enhanced capacity for self-assessing their designs and problem-solving approaches (Drinkwater et al., 2025). The benefits multiply when feedback modifies students' thought processes rather than merely correcting surface-level errors. Moreover, research confirms that effective engagement in both feedback roles helps students develop self-assessment abilities while improving team dynamics, fostering self-regulation behaviours, and supporting broader professional skill development (Nicol et al., 2014).

For you as educators, this dual role has practical implications. Rather than treating peer feedback as an occasional assessment activity, design learning experiences where students regularly practise both giving and receiving feedback. This means building structured opportunities for students to evaluate others' work, provide constructive critique, and then apply similar critical thinking to their own designs. The goal is not just to distribute the workload of providing feedback, but to develop students' professional competencies in both directions simultaneously.

2.3 *Assessment challenges and emerging solutions*

Despite the established importance of feedback literacy, assessing these competencies in engineering remains underdeveloped. The need for engineering-specific tools becomes clear when examining recent work on peer feedback quality: Drinkwater Gregg et al. (2025) found that in first-year engineering students' peer feedback comments, over 60% failed to identify performance gaps, approximately 70% provided no actionable recommendations, and fewer than 3% achieved overall high-quality status. These findings suggest that while students recognise positive contributions, they struggle with identifying improvement areas and providing actionable guidance, skills particularly critical in engineering's iterative design processes. This means that simply asking students to review each other's work without scaffolding will produce superficial comments that do not support learning. Students need explicit instruction in what good feedback looks like, supported by models, rubrics, and progressively complex feedback tasks (see Section 3 for implementation approaches).

A further challenge is that much of the feedback exchange in engineering education and practice occurs through informal oral conversation rather than structured written forms, including during capstone design projects, co-op experiences, and active learning classrooms. This spontaneous feedback often carries substantial learning value but is difficult to capture and assess systematically (Nikolic et al., 2018), making this an important gap for both researchers and practitioners to address.

Several instruments now exist with evidence of validity for measuring feedback literacy in higher education contexts, though none were developed specifically for engineering. They vary meaningfully in what they measure and how. Some focus on attitudes and dispositions toward feedback (Yildiz et al., 2022; Zhan, 2022), while others capture observable behaviours, i.e., what students actually do when engaging with feedback (Dawson et al., 2024). Instruments also differ in the feedback modes they cover: some address only written or peer feedback (Dong et al., 2023; Yu et al., 2022), while others measure oral, written, rubric-based, peer, and self-assessment modes within a single scale (Liao, 2021). Since none of these instruments have yet been adapted and validated for engineering contexts, we encourage you to examine what each measures and how, consider which modes and behaviours are most relevant to your specific module or programme, and treat any instrument you choose as a starting point to iterate on.

3 Forms of implementation

While theoretical frameworks for feedback literacy continue to evolve, translating these concepts into specific, evidence-based practices for engineering education requires moving beyond existing systems to address the dynamic, collaborative nature of engineering practice. In this section, we examine four complementary approaches for implementing feedback literacy development within the unique characteristics of engineering education: peer feedback structures that naturally create opportunities for students to practise both giving and receiving critique; engineering studios that provide systematic frameworks for authentic, iterative feedback exchange; self-reflection methods that support both the development and assessment of feedback literacy skills; and emerging generative AI technologies that offer scalable solutions for both fostering and measuring feedback literacy in complex engineering contexts.

3.1 Peer feedback for engineering students

Experiential learning approaches, including problem-based learning (PBL), capstone design modules, first-year engineering experiences, and laboratory modules, emphasise higher-order thinking skills by engaging students in real-world problem-solving scenarios (Tembrevilla et al., 2024). These approaches simultaneously develop essential professional skills (Borrego et al., 2010), including communication (Beagon et al., 2019), conflict management (Ryan et al., 2023), and collaboration with diverse team members (Zhang & Ma, 2023), making them ideal environments for feedback literacy development.

Within these structures, students naturally alternate between feedback roles as they evaluate teammates and receive input from peers and instructors (Kokotsaki et al., 2016). This dual engagement serves multiple purposes: it informs you about team dynamics, helps teams improve their performance, and, critically, provides authentic opportunities for students to practise both giving and receiving feedback (Mentzer et al., 2015). Research shows peer feedback can be as effective as instructor feedback when properly implemented, because giving feedback forces students to think deeper about design quality, including in their own work (Ekoniak & Paretti, 2018; Rukmono

& Chaudron, 2022). When implemented with training and reflection components, peer feedback serves as a powerful tool for developing both feedback literacy and engineering design understanding (Mattucci et al., 2018).

The quality of peer feedback also depends heavily on proper training. Trained peer reviewers provided feedback that better matched effective practices—more coaching/readerly comments, more content focus, and a more positive tone— than untrained instructors, highlighting the importance of structured preparation (Ekoniak & Paretti, 2018). Moreover, as students participate in peer feedback activities, they become more discerning evaluators as their work quality improves, aligning assessments with instructor ratings when given comparative benchmarks (Revilla-Cuesta et al., 2024). However, challenges remain in both roles: as providers, first-year engineering students often lack training in writing effective feedback, resulting in short phrases or comments that are not actionable (Drinkwater Gregg et al., 2025); as receivers, student motivation significantly affects their willingness to incorporate suggestions (Berry et al., 2022).

Commonly used peer evaluation platforms such as CATME, ITP Metrics, and TEAMMATES facilitate peer feedback interactions but provide minimal instruction for either giving or receiving feedback, leading to considerable variation in both feedback quality and utilisation (Burgess et al., 2021; Sajadi et al., 2024). These challenges are compounded when feedback serves summative assessment purposes, as students avoid providing honest critiques that might negatively impact teammates' grades (Sridharan et al., 2019). Regardless of the platform you use, explicit instruction in both giving and receiving feedback is essential for developing true feedback literacy.

Structured peer and external feedback in senior design

The advisory board model developed by Werth et al. (2026) illustrates how peer and external feedback structures can be embedded systematically across a senior design module. Rather than treating feedback as a single review event, this model distributes critique across the design cycle and requires students not only to receive comments, but also to generate, interpret, and act on them through documented module artefacts.

One component is a student advisory board system in which current students from other design teams serve in defined review roles mirroring common professional perspectives, including technical, clinical, regulatory, intellectual property, and business roles. Boards meet at multiple points across the project lifecycle, creating iterative opportunities for critique as teams refine problem definitions, design choices, and implementation plans. Each advisor submits an individual report identifying strengths, risks, and actionable recommendations, and the instructional team evaluates report quality to maintain norms for specificity and actionability, while preserving the peer-centred nature of the exchange (Nicol et al., 2014) as shown in Example 1.

Example 1. Individual advisory board report assignment

As an advisory board member, your job is to independently evaluate the team's progress and provide helpful, constructive feedback from the perspective of your assigned advisory role. Your report should identify strengths, point out risks or gaps, and suggest practical next steps. This assignment is meant to help you practice technical evaluation, professional communication, and strategic thinking.

Each report should be one to two pages and include the following sections:

- *Executive summary: a brief overview of the team's progress, major strengths, and main areas for improvement.*
- *Achievements: what has the team done well so far? Highlight important accomplishments, strong ideas, or notable progress toward their goals.*
- *Risks: describe current challenges or concerns, such as technical issues, logistical barriers, or team-related problems. Use specific examples when possible.*
- *Recommendations: provide three to four specific, actionable suggestions to help the team improve. These may include next steps, ways to address challenges, possible collaborations with other teams, or useful stakeholder connections.*

In addition to the report, include your meeting notes as an appendix. These do not need to be formal; bullet points are fine. Your notes should summarize the advisory board discussion and capture useful feedback on both the substance of the project and the quality of the presentation.

The second component is a sequence of individual stakeholder interviews in which students solicit perspectives from relevant external stakeholders and document what was learned through short written analyses. In combination with the advisory board structure, these interviews broaden the range of evaluative input students must navigate and create repeated opportunities to connect feedback to design criteria and constraints.

A key feature of this model is that feedback uptake is made visible. After each advisory board round, teams produce a response-to-advice that triages recommendations, justifies which suggestions will be accepted, modified, or deferred, and records resulting changes. Teams also complete a recap synthesising lessons from other groups' reviews, moving feedback from simple receipt toward selective use and enactment.

3.2 Using engineering studios to make critique routine and visible

Recent work by Fuchs et al. (2026) demonstrates how studio-based pedagogy can systematically address feedback literacy development. Unlike conventional approaches that isolate feedback to discrete evaluation moments, their studio model

creates structured opportunities for students to transition between providing and receiving feedback throughout the design process. Three key feedback modalities are incorporated: real-time informal consultations during problem solving, where instructors circulate to visit student teams at their workstations (desk visits); structured pin-up critiques where teams present in-progress work for class examination, enabling both intra- and inter-team idea sharing; and final reviews, where students present their finished work products to the class for review and critique, integrating engineering analysis with design thinking (Fig. 2.12.2).

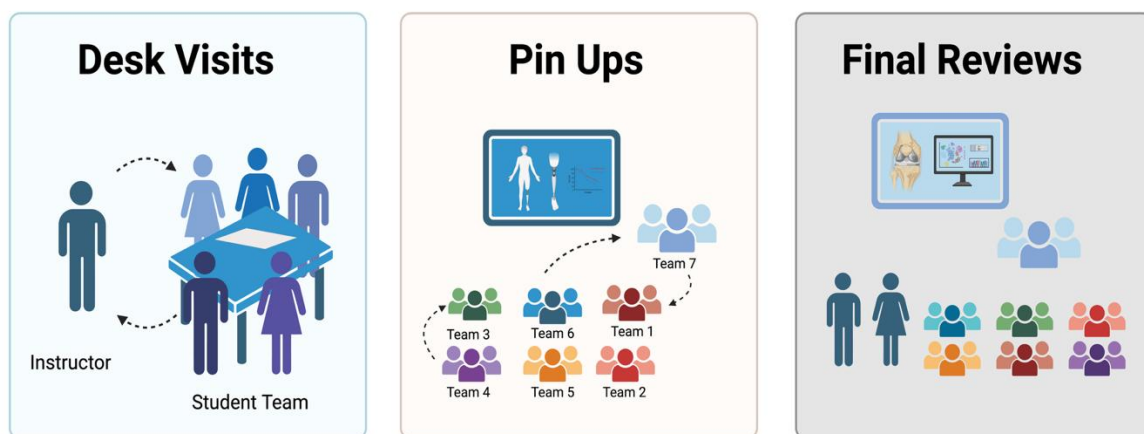


Figure 2.12.2: Three-tiered feedback framework in engineering design studios (Fuchs et al., 2026), spanning real-time desk consultations, structured pin-up critiques of work-in-progress, and final reviews integrating engineering analysis with design thinking. Own Work by Fuchs, Meyer, Butcher, and Werth (2026).

Studios scaffold feedback literacy through the studio's structured, multi-step process, which directs students to focus on specific aspects when giving feedback, such as whether all constraints were identified, if the system model is accurate, or if proposed solutions are feasible. Through repeated practice with giving feedback, students develop both technical standards and professional communication skills. While direct measurements of feedback literacy improvements have not yet been conducted, this framework establishes a solid foundation for treating feedback as fundamental to engineering practice rather than an add-on evaluation exercise.

For educators considering studio approaches, you do not need three-hour sessions or a complete curriculum redesign to adopt studio principles. The key elements, including regular informal feedback during work time, structured peer critique sessions, and scaffolded frameworks that guide what to look for, can be integrated into existing modules. Consider starting with structured peer reviews using specific prompts that focus students' attention on technical criteria, then gradually building in more frequent, informal feedback opportunities during class time.

3.3 Developing feedback literacy through self-reflection

Self-reflection has emerged as both a catalyst for feedback literacy development and a valuable tool for tracking students' progress. Coppens et al. (2023, 2025) developed an approach using reflective logs, i.e., structured written records in which students describe and analyse a meaningful feedback experience, capturing actual behaviour rather than stated intentions. Longitudinal analysis revealed significant growth in both reflection quality and feedback literacy across the undergraduate programme: students demonstrating advanced feedback literacy characteristics increased from 14% in Year 1, semester 2 to 75% in Year 3, semester 2 (Coppens et al., 2024). Initially, 63% of reflective logs remained at the understanding level, one of four reflection levels used in the study alongside non-reflection, reflection, and critical reflection. At this level, students recognise the relevance of feedback and may explain how it could be applied, but do not yet clearly commit to using it again in future work. This is unsurprising, as engineering students often struggle with reflection since it differs significantly from typical engineering assignments (Coppens et al., 2023). However, sustained implementation throughout undergraduate years led to significant improvements, helping students move beyond understanding toward fuller reflection, where they connect feedback to personal experience, explain why it matters, and identify implications for future learning. This suggests that consistent exposure to reflective practices can develop both reflective capacity and feedback literacy over time.

For educators implementing reflection, expect initial resistance as engineering students may view reflection as irrelevant compared to technical work. Start with structured prompts that connect directly to engineering practice, such as *'How did you use feedback from your design review to improve your prototype?'* rather than open-ended questions like *'Reflect on your learning.'* Build reflection into existing portfolio systems rather than creating additional assessment burdens and be patient as improvement takes consistent practice over multiple terms.

3.3 Scaling feedback literacy development

One promising application of generative AI for supporting self-reflection is adaptive question generation. Mburu et al. (2025) developed an AI-driven survey tool that generates contextually relevant questions in response to individual student answers in real time, meaning a student who writes a superficial reflection receives follow-up questions that probe more deeply, while a student demonstrating sophisticated thinking receives questions that extend their analysis further. This addresses a core challenge in engineering education: prompting students unfamiliar with reflective practice to engage more meaningfully, without requiring an instructor to respond to every submission individually.

This potential represents part of a broader trend in GenAI applications for educational feedback. GenAI offers promising solutions for personalised feedback assistance (Zhan et al., 2025), and emerging findings suggest that AI-generated feedback can improve student performance and is often rated highly by experts for accuracy and clarity

(Meyer et al., 2024; Steiss et al., 2024). For example, Meyer et al. (2024) found that students receiving feedback generated by a large language model improved their revision performance and reported higher motivation, more positive emotions, and greater perceived usefulness than students given only a general revision instruction, though the study did not compare AI feedback with teacher feedback. In a follow-up study, Meyer et al. (2026) compared AI-generated feedback with teacher feedback showing that the immediately provided AI feedback when compared to the delayed AI and teacher feedback had motivational benefits and was perceived as more useful. Unlike human feedback sources, generative AI is readily available without scheduling conflicts and creates a less intimidating environment for students who might hesitate to seek feedback due to social anxieties (Zhan et al., 2025). In first-year problem-based learning modules, large language models significantly improved peer feedback quality by making comments more constructive and actionable and providing meaningful comparisons between students' self-evaluations and peer assessment (Sajadi et al., 2024). While preliminary evidence from other disciplines suggests similar potential for AI-supported peer feedback systems (Guo et al., 2025), more research is needed to establish their effectiveness specifically within engineering contexts.

Table 2.12.1: Observational feedback tool (Fuchs et al., 2024). When observing a feedback interaction, select one descriptor from each column to categorise the context, the feedback given, and the student response to feedback.

<i>Context</i>		<i>Feedback given</i>		<i>Response to feedback</i>	
Prompted by	Feedback was	Nature	Focus level	Cognitive	Emotional
Group	Directive	Gaps in status	Task	Increased efforts	Positive
Instructors	Facilitative	Provides information	Process	Lower expectations or standards	Neutral
Students outside group		Reduces misconceptions	Self- and/or group regulation	Reject the feedback,	Negative
		Other	Self/group	Abandon efforts to achieve the goal	

For educators considering AI tools, be aware that these tools are not equally effective for all students. Students with stronger feedback literacy tend to engage more productively with AI-generated feedback, while those with weaker feedback literacy may find complex feedback overwhelming (Weidlich et al., 2025a, 2025b). This

suggests that students' existing feedback literacy likely shapes how much they benefit from these tools. This highlights the importance of personalised feedback design, particularly in engineering contexts given the complexity of collaborative tasks. A practical starting point is to help students develop habits of critical engagement with AI-generated suggestions. Encourage students to evaluate and question feedback rather than accept it uncritically. It may also be worth introducing these tools gradually, beginning with lower-stakes or more straightforward assignment types such as written reports or reflections, to allow both you and your students to build familiarity before expanding to more complex engineering tasks.

Using AI to analyse feedback interactions in your classroom

Emerging research shows how generative AI can also serve as an analytical tool for understanding feedback interaction dynamics. Fuchs et al. (2024) developed an observational framework that categorises feedback interactions across multiple dimensions: context and timing, feedback nature (directive versus facilitative), focus level (task, process, self-regulation, or self and group), and the immediate emotional and cognitive responses these interactions elicit from students (Table 2.12.1). Their protocol captures feedback modalities ranging from planned instructor desk visits to spontaneous peer interactions, enabling real-time documentation of how different approaches impact student engagement (see Example 2).

Example 2. Observing a desk visit during a studio session

Scenario: during a modelling activity, an instructor visits a team struggling with their system equations. The instructor asks: "Walk me through how you derived this equation. What assumptions did you make about flow rate?" The students explain their thinking, and the instructor responds: "Good start. What happens to your equation if the flow isn't constant? Think about how that affects your boundary conditions." One student looks at the equation and says, "Oh! So, we'd need a time-dependent term here..." Another student adds excitedly, "Wait, that's why our simulation kept crashing — we were treating it as steady-state!" The team immediately starts redrawing their diagrams and revising their equations. We can use the framework to categorise this interaction as shown in Table 12.2.2.

Table 12.2.2: Desk visit example of use of framework

Context		Feedback given		Response to feedback	
Prompted by	Feedback was	Nature	Focus level	Cognitive	Emotional
Instructor	Facilitative	Reduces misconceptions	Process	Increased	Positive

Why these classifications?

- *Facilitative: used questions to guide students to their own insights rather than giving direct answers.*

- *Reduces misconceptions: corrected their assumption about constant flow.*
- *Process level: focused on how they approach deriving equations, not just the final answer.*

This systematic categorisation revealed critical insights. For example, conflicting guidance between multiple instructors dramatically reduced student engagement and created learning-disrupting frustration, while validating feedback during class-wide discussions maintained high engagement levels (Fuchs et al., 2024). These findings show that how and when you provide feedback matters as much as what you say, something that can be difficult to notice in the moment while teaching. The framework addresses this by categorising feedback interactions in real time and tracking student responses, revealing how identical feedback types produce different reactions depending on timing, context, and consistency with previous guidance.

Augmented by AI-generated synthetic data for training natural language processing models, the framework enables instructors to identify patterns in their feedback delivery that may not be apparent during sessions (Fuchs et al., 2025). However, you can apply the underlying principle without AI: record studio sessions or desk consultations and review them later, or have a colleague observe and categorise your feedback using the framework (Table 2.12.1). The key is systematic observation, whether AI-aided or manual, to make your feedback patterns visible and actionable.

4 Recommendations for implementation

Engineering-specific evidence is still emerging, so the recommendations below combine established feedback literacy theory with implementation patterns that fit common engineering learning environments. We recommend using these as a starting point: pilot one or two, gather information about student uptake, and iterate as needed. These recommendations on developing feedback literacy complement the broader feedback strategies discussed in Chapter 2.11; use both chapters together to create comprehensive feedback environments that both deliver effective feedback and develop students' capacity to use it.

Adapt and validate for your context. Interventions and assessment tools developed for general educational contexts require careful adaptation within engineering-specific settings. Several validated feedback literacy instruments exist, each measuring different modes and behaviours. Examine what each measures, consider which aspects are most relevant to your module or programme, and treat any instrument you adopt as a starting point rather than a fixed tool. AI technologies offer promising pathways for accelerating engineering-specific feedback literacy research in the coming years.

Leverage engineering's collaborative nature to develop dual competency. Engineering projects naturally position students as both evaluators and recipients. Capitalise on this by explicitly training students in both roles rather than treating peer feedback as an afterthought to instructor assessment. Integrate feedback literacy development within existing activities — studios, capstone modules, problem-based learning — and

enhance these structures with explicit scaffolding rather than adding separate training modules that may seem disconnected from core engineering practice.

Use AI thoughtfully to scale support, not replace instruction. Generative AI offers promising solutions for scaling feedback literacy development through enhanced peer feedback quality, personalised support, and analytical tools for understanding feedback patterns. However, its effectiveness depends significantly on students' existing feedback literacy levels, highlighting the need for thoughtful integration rather than wholesale replacement of human feedback processes. Move beyond simple rating systems towards platforms that scaffold both feedback provision and reception skills.

Implement systematic reflection across the curriculum. Self-reflection serves dual purposes: it develops feedback literacy and provides a tool for tracking progress. Whilst engineering students often struggle with reflection initially, sustained implementation throughout undergraduate programmes can develop both capacities simultaneously. Embed reflective logs across multiple terms using structured but non-directive prompts, such as *"How did you contribute to obtaining or processing the feedback?"* and *"How does the feedback help you to better assess your own work and that of others?"* Focus on dual assessment frameworks that evaluate both reflection quality and feedback literacy. Address initial resistance by recognising that engineering students may demonstrate limited reflection levels initially but can develop these skills over time when reflection is embedded within existing portfolio systems or module requirements rather than creating additional assessment burdens.

We encourage practitioners to stay engaged with emerging feedback literacy research and share insights from your implementations, helping build the engineering-specific evidence this field needs. Reflect systematically on your own feedback practices, just as you ask students to do, and use those observations to refine your approaches over time. Should you wish to further deepen your knowledge on feedback literacy, we recommend Carless (2022), Lee and Moore (2024) and Little et al. (2023).

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AI statement

During the preparation of this work, the authors used ChatGPT5 in order to improve language and readability. After using this tool, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

Contributor statement

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2.13

Fostering Self-Regulated Learning Among Engineering Students

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Self-regulated learning (SRL) is increasingly recognised as a core competency for engineering students, who must navigate complex, multidisciplinary problems and continuously adapt their learning throughout their careers. This chapter introduces SRL through three complementary theoretical models: Zimmerman’s cyclical phases, Boekaerts’ dual processing model, and Hadwin et al.’s socially shared regulation of learning framework, thus highlighting the cognitive, emotional, and social dimensions that shape how students plan, monitor, and evaluate their learning. Eight SRL intervention archetypes are used to provide a practical structure for educators to design or select interventions that fit their context. To illustrate how SRL can be fostered in practice, we present three case studies from different institutional and cultural contexts, demonstrating varied approaches to embedding SRL through reflection, peer support, direct instruction, and technology-enhanced scaffolding. The chapter concludes with ten recommendations for creating effective interventions that foster SRL among engineering students.

1 Definition: the concept of self-regulated learning

1.1 What is self-regulated learning?

Self-regulated learning (SRL) involves proactively setting goals, planning how to achieve them, self-motivation, monitoring progress, and reflecting on what was effective and what was not (Zimmerman, 2002). It is a process characterised by an internal feedback loop through which learners actively manage their learning (Butler & Winne, 1995). Learners take agency over their own learning process, continually adapting it to specific learning tasks and improving it over time (Butler & Winne, 1995; Zimmerman, 2002).

1.2 Theoretical models of SRL

Various theoretical frameworks describe the components, processes, and strategies underpinning SRL (Panadero, 2017). Each offers a distinct perspective and emphasis. This chapter presents three widely used models that provide complementary insights into the construct of SRL: Zimmerman's cyclical phases model, Boekaerts' dual processing model, and Hadwin et al.'s socially shared regulation of learning framework. These models emphasise the individual, emotional, and social dimensions of SRL, respectively.

Zimmerman's cyclical phases model – individual dimension

Zimmerman's model (2002) is characterised by its cyclical nature and involves three learning phases: (1) the forethought phase, in which learners set goals for themselves and determine what steps to take to achieve those goals; (2) the performance phase, in which learners implement their chosen strategies and monitor their learning activity and progress towards the goal; and (3) the self-reflection phase, during which learners look back on whether they have achieved their original goal and evaluate the effectiveness of the learning activity. The self-reflection phase informs the next forethought phase, underscoring the cyclical nature of SRL, making it a dynamic and evolving process of continuous improvement.

Boekaerts' dual processing model – emotional dimension

Boekaerts' dual processing model (Boekaerts, 2011) states that learners regulate their behaviour through two parallel pathways, and that emotions triggered by a task determine which pathway becomes dominant.

Learners follow the *mastery pathway* when they experience positive and manageable emotions toward a task. Their learning goals feel meaningful and attainable, which creates alignment between what the task requires and their own well-being. On this pathway, learners invest effort, develop competencies, and use effective learning strategies. Learners shift into the *well-being pathway* when a task triggers negative emotions, such as stress, confusion, frustration, or threat. Here the learner's main goal becomes protecting their emotional well-being, not completing the task. This may result in avoiding the task, postponing work, or narrowing attention to reduce discomfort. Although learners may initially move into the well-being pathway, they

can shift back toward the mastery pathway when they feel a sense of commitment, for example a commitment to personal goals, to an assignment deadline, to their project team or teacher, or to their own standards of performance. These commitments give learners a reason to re-engage with the task, even when emotions can still be negative. This shift can be supported by *internal factors*, such as autonomous motivation, self-efficacy, or personal values, or *external factors*, such as expectations from peers, instructors, or assessment requirements.

Boekaert's dual processing model highlights that emotions are not side effects of learning, but that they actively shape SRL. Learners' behaviour under time pressure, performance demands, or uncertainty can be understood as movement between the two pathways. Effective SRL support therefore requires focusing not only on strategies, but also on the emotional context in which students regulate their learning.

Socially shared regulation of learning (SSRL) – social dimension

Hadwin et al. (2011) state that regulation occurs in social and interactive settings, highlighting how SRL is not only an individual process. It distinguishes three modes of regulation in collaborative settings: (1) self-regulation at the individual level (SRL), in which learners adapt their own actions to group interactions; (2) co-regulation (CoRL), in which one person takes the lead in regulation, motivating others to practise regulatory behaviours; and (3) socially shared regulation (SSRL), in which the whole group deliberately and jointly regulates their learning.

This model is especially relevant in engineering education, where teamwork is central to capstone projects, design challenges, and problem- and inquiry-based learning environments.

1.3 SRL and related competencies

As shown above, SRL models vary in focus. Some emphasise SRL's cyclical nature (Zimmerman, 2002), others its emotional (Boekaerts, 2011) or social dimensions (Hadwin et al., 2011). These models also differ in whether related competencies are seen as influences or subcomponents of SRL. This chapter focuses on four competencies that are important for success in engineering education and practice, regardless of their classification: self-direction (Conway et al., 2022), self-reflection (Zimmerman & Moylan, 2009), autonomous motivation (Schunk & Zimmerman, 2007), and feedback literacy (Butler & Winne, 1995). Table 2.13.1. presents how these four competencies are connected to the three SRL models.

Table 2.13.1. Mapping between the four competencies and the SRL models of Zimmerman, Boekaerts, and Hadwin.

	<i>Zimmerman (individual)</i>	<i>Boekaerts (emotional)</i>	<i>Hadwin (social)</i>
<i>Self-direction</i>	The forethought phase includes planning, goal-setting, and strategy selection. In the performance phase the learner has to maintain direction. During the self-reflection phase a learner should redirect and redefine the (learning) direction.	Learners switch between mastery and well-being pathways, exercising agency when deciding how to proceed with a task.	Groups co-construct goals, assign roles, and coordinate strategies in shared regulation episodes. Within the group, individuals also have to be self-directed.
<i>Self-reflection</i>	Central in the self-reflection phase (self-evaluation, attribution, adaptive reactions).	Emotional awareness and meaning-making drive shifts between pathways; reflection helps learners re-engage.	Teams engage in collective monitoring and reflection on progress and decisions. Individuals in teams need to self-reflect.
<i>Autonomous motivation</i>	The forethought phase includes self-efficacy, task value, outcome expectations, and motivation beliefs. The performance and self-reflection phase requires self-control and self-reflection, which are subject to motivation.	Motivation drives movement from the well-being pathway back to the mastery pathway; learners persist because goals matter.	Group belonging and collective goals can strengthen motivation, but this is not the primary focus of the model.
<i>Feedback literacy</i>	Feedback (internal and external) informs monitoring and adaptation within and across cycles.	Emotional reactions affect how feedback is received and acted upon.	Co- and shared regulation depend on giving and receiving feedback.

2 SRL across engineering education

Effective SRL helps students take ownership of their learning and improve it over time. While valuable across disciplines, it is particularly important in engineering education, which often employs approaches such as problem-based and collaborative learning that require students to become autonomous, adaptable learners (Hernández-de Menéndez et al., 2019). Engineering programmes expect students to develop competencies such as critical thinking, adaptability, and resilience, which can be fostered through SRL. Such competencies are crucial not only for academic success, but also for professional practice in engineering. As engineering is a rapidly evolving field, professional engineers must be capable lifelong learners to remain competitive. SRL is recognised as a core component of lifelong learning (Van den Broeck et al., 2024b). However, recent research suggests that engineering students may not attain a sufficient level of SRL by graduation, leading to a call from the industry for higher education to incorporate SRL development in engineering programmes (Tuyaerts et al., 2025b).

This importance of SRL is reflected in engineering education frameworks and professional standards worldwide. The ENAEE (2021), which oversees the EUR-ACE framework used across Europe, expects graduates to be prepared for independent lifelong learning. SRL supports autonomous and adaptive learning, contributing directly to this outcome. In the United States, the American Society for Engineering Education highlights persistence, motivation, and critical thinking as essential graduate attributes (Agrawal & Harrington-Hurd, 2016), competencies that are either part of or supported by SRL. Furthermore, ABET, the Accreditation Board for Engineering and Technology which sets widely used criteria for engineering programs in the United States and defines core student outcomes expected of engineering graduates (ABET, 2024), emphasises student outcomes such as problem solving, teamwork, professional judgement, feedback literacy, and the ability to acquire new knowledge independently. These are all capabilities that rely strongly on SRL processes. SRL supports these outcomes by helping students plan and monitor their work (self-direction), evaluate and improve their performance (self-reflection), stay motivated through complex tasks (autonomous motivation), and make effective use of feedback (feedback literacy).

3 Forms of implementation

3.1 SRL intervention archetypes

A recent systematic literature review by Tuyaerts et al. (2025a) identified eight distinct types of interventions designed to foster SRL in higher education, referred to as SRL intervention archetypes. Tuyaerts' typology with eight archetypes aims to offer a practical typology to understand, compare, and select approaches for supporting SRL across disciplines. Although these archetypes provide a helpful structure for navigating the wide variety of SRL interventions, they should not be viewed as exhaustive, mutually exclusive, or universally applicable. Educators can combine elements across archetypes or adapt them to fit their instructional goals and constraints.

T1: Indirect technology-facilitated SRL instruction interventions without teacher feedback

T1 interventions incorporate digital tools into their setup. Rather than teaching SRL directly, they guide students through SRL processes such as planning, monitoring, and reflecting, potentially without students realising they are engaging in SRL. This approach may help students develop habits that lead to automatic regulation of learning, based on their experience with the intervention. Teacher feedback is absent, freeing up staff resources, though feedback may be generated automatically via technology. For example, interventions may display analytics in a learning management system (Banihashem et al., 2022), provide automatic feedback on assignment correctness (Daradoumis et al., 2021), or support learning by offering prompts via a pedagogical agent (Cerezo et al., 2020).

T2: Indirect SRL instruction interventions with teacher feedback

T2 interventions combine indirect SRL instruction, where students engage in the SRL cycle without explicit instruction on SRL concepts with teacher feedback. Teacher-provided feedback may relate to module content or learning processes, but not to SRL itself, as students do not receive direct SRL instruction. Students can use this feedback to learn about their performance, informing their own evaluation processes and indirectly training their self-reflection competency.

T3: Direct standalone SRL instruction interventions

T3 interventions provide direct SRL instruction outside the regular curriculum, such as in an elective module (Reeves & Stich, 2011). They are typically flexible and can be offered to students across programmes as a separate module or training, allowing them to be easily reused. Direct SRL instruction allows students to learn about SRL theory, such as Zimmerman's cyclical model, and strategies like goal setting or self-evaluation. Facilitators may need to familiarise themselves with SRL theory and concepts before they can effectively deliver these interventions.

T4: Direct embedded SRL instruction interventions

Unlike the standalone interventions of T3, T4 interventions are integrated into subject-specific content and modules. This approach demonstrates the relevance of SRL to students' academic work and allows them to apply SRL strategies in authentic contexts. Students receive direct SRL instruction and apply it to real learning tasks. Subject-specific strategies, such as vocabulary learning (Zhang et al., 2024), help bridge SRL theory and practice, encouraging SRL as a natural part of the learning experience.

T5: Peer-driven interventions

T5 interventions rely on peer interaction to drive SRL development. Peers can both refer to more experienced students acting as tutors (Fernandez-Martin et al., 2022) or monitors (Reeves & Stich, 2011), or to students of the same level who provide support as equals, such as peer assessment or feedback (Contreras Soto et al., 2023) and peer-led study groups (Atwa et al., 2019). What distinguishes this type is the

intentional and structured peer engagement, which goes beyond typical group work. If direct SRL instruction is included, students may require training to support others effectively.

T6: Self-paced self-study interventions

These interventions allow students to decide when and how to engage with the learning materials. Once content, such as a study skills app (Baars et al., 2022), is prepared and made available, students work through it independently, without scheduled sessions. This format promotes student autonomy and responsibility, key elements of learner agency and SRL. While setup requires preparation and development, ongoing facilitation is minimal.

T7: Documented reflection-driven interventions

These interventions use structured written reflections to support SRL through introspection. Formats such as learning diaries (Fabrizz et al., 2014) and online portfolios (Nguyen & Ikeda, 2015) help students reflect on their learning, track progress, and identify strengths and weaknesses. The reflective process over time allows students to revisit entries to support their learning process.

T8: Personalised data-driven interventions

These interventions use technology-mediated feedback and content to individual students based on data collected during the intervention. As a result, all such interventions require technological support. Tools such as learning analytics dashboards (Banihashem et al., 2022; Sauchelli et al., 2024) and AI tutors (Lee et al., 2024), aim to provide personalised feedback (Chu et al., 2023) or reflection prompts (Cerezo et al., 2020). Personalisation is automated, making these interventions scalable and responsive to individual needs and development stages without additional effort.

Connecting archetypes to the three SRL models

Although the archetypes leave ample room for concretisation and specialisation, it is useful to consider how they generally align with the main perspectives of the three theoretical SRL models presented earlier. Zimmerman's model emphasises a cyclical and predominantly individual form of regulation, Boekaerts' model foregrounds the emotional and motivational dimension of regulation, and Hadwin's model highlights the social dimension through co- and socially shared regulation. Table 2.13.2 presents a connection between the eight SRL archetypes and the three SRL models, illustrating where strong, moderate, or limited alignment can typically be expected.

Table 2.13.2: Connecting the eight SRL intervention archetypes to the three SRL models. Dots represent the degree to which the SRL intervention archetype is connected to the SRL model.

<i>SRL intervention archetype</i>	<i>Zimmerman (individual)</i>	<i>Boekaerts (emotional)</i>	<i>Hadwin (social)</i>
T1: indirect tech-facilitated (no teacher feedback)	••	•	•
T2: indirect SRL with teacher feedback	••	••	•
T3: direct standalone SRL instruction	•	•	•
T4: direct embedded SRL instruction	•••	••	••
T5: peer-driven interventions	••	••	•••
T6: self-paced self-study	•	•	•
T7: documented reflection-driven	•••	••	•
T8: personalised data-driven	••	•	•

Table 2.13.3: Mapping between the three SRL models and the three case studies. Dots represent the degree to which the case study is mapped to the SRL model.

	<i>Zimmerman (individual)</i>	<i>Boekaerts (emotional)</i>	<i>Hadwin (social)</i>
Case study 1: Process-based learning through reflection cycles (TU/e)	••	•	•••
Case study 2: Reflection for learning equity (MUST)	•••	••	•
Case study 3: Longitudinal SRL intervention (KU Leuven)	•••	•	•

3.2 Three case studies

This section presents three case studies illustrating how SRL interventions can be implemented in practice. We connect these case studies explicitly to the three theoretical SRL models of Section 1 (Table 2.13.3) and the eight SRL archetypes of Section 3 (Table 2.13.4). Hereby we provide practitioners with real-world examples on how to connect SRL interventions to SRL theory, Tuyaerts' SRL intervention typology, and particular SRL competencies.

Table 2.13.4: Mapping of case studies to the SRL archetypes. ●●● = primary alignment/core design; ●● secondary alignment (intentional but not central); ● supporting alignment (present but not core); ○ not applicable/no meaningful alignment.

<i>SRL archetype</i>	<i>Case 1: process-based learning through reflection cycles (TU/e)</i>	<i>Case 2: reflection for learning equity (MUST)</i>	<i>Case 3: longitudinal SRL intervention (KU Leuven)</i>
<i>T1: indirect tech-facilitated SRL (no teacher feedback)</i>	○	○	○
<i>T2: indirect SRL instruction (teacher feedback)</i>	● (coach feedback on process)	●● (instructor reading & guiding journals)	○
<i>T3: direct standalone SRL instruction</i>	○	○	○
<i>T4: direct embedded SRL instruction</i>	○	○	●●● (core design across 3-year curriculum)
<i>T5: peer-driven interventions</i>	●● (peer coaches in central role)	○	○
<i>T6: self-paced self-study</i>	○	● (individually paced journaling)	● (self-paced SRL tasks across semesters)
<i>T7: documented reflection-driven interventions</i>	●●● (repeated, structured, written reflection)	●●● (weekly reflections)	●● (reflections across modules/years)
<i>T8: personalised data-driven interventions</i>	○	○	○

The three case studies are drawn from the authors' institutional practice across Eindhoven University of Technology (TU/e) in the Netherlands, Mbarara University of Science & Technology (MUST) in Uganda, and KU Leuven in Belgium. Each was

implemented by the authors or close collaborators within their regular teaching and programme-level responsibilities.

Case 1: Process-based learning through reflection cycles

Context. The Innovation Space Bachelor End Project (ISBEP) is a challenge-based learning module at Eindhoven University of Technology (TU/e) in which interdisciplinary student teams work on open-ended, real-world challenges (Ruijten-Dodoiu et al., 2024). Students from different engineering programmes collaborate with external stakeholders and are supported by a network of coaches and academic supervisors. The module is positioned at the end of the bachelor programme and is designed to foster both disciplinary knowledge and broader professional competencies such as SRL, collaboration, systems thinking, and reflection. The module was taught by one of the authors of this chapter and has the following intended learning outcomes (ILO):

Students are able to:

- Identify the needs of different stakeholders and integrate them in a viable solution;
- Identify the interdisciplinary problem that needs to be solved and its disciplinary components;
- Reflect on the role that they have played in the interdisciplinary team, and its impact on professional identity;
- Manage a situation where there is no clear answer to their problem;
- Integrate the individual components into a working/experiential demonstrator;
- apply the knowledge from different disciplines in a project and integrate them into a viable solution;
- communicate and collaborate with people from other disciplines.

Intervention design. This intervention implemented a process-based learning approach to support the development of broader professional competencies. The core idea was to move beyond traditional assessment of learning and instead focus on assessment for learning. This was operationalised through a developmental framework that described learning outcomes across four stages: beginning, emerging, proficient, and advanced. These stages were applied to a set of intended learning outcomes (ILOs) that captured key aspects of competence development in ISBEP. Each ILO was described in terms of observable behaviours and increasing levels of independence, providing students with a clear structure for self-assessment and growth.

Throughout the module, students engaged in a recurring reflection cycle, structured around seven time points. At each point, they assessed their own development, reflected on their learning process, and received narrative feedback from their process coach. These reflections were guided by prompts that encouraged students to articulate their goals, identify challenges, and plan next steps. The process was designed to support SRL by making development visible and actionable. In ISBEP, process coaches, often experienced students or alumni, are trained to guide students

through the reflection cycle, provide formative feedback, and help them interpret their development in relation to the ILOs. These coaches used the reflections to tailor their guidance and to monitor student progress over time. Hence, SRL development is driven by peers, acting as process coaches, and repeated reflection. The intervention draws on active learning in authentic engineering contexts.

Implementation and sample size. The intervention was implemented with 29 Year 3 engineering bachelor students enrolled in the ISBEP module.

Data collection. Data included seven rounds of written reflections, narrative feedback from peer coaches, student interviews, and module evaluations conducted at the end of the module.

Data analysis. Reflections were analysed using qualitative coding focused on SRL behaviours (planning, monitoring, reflection), and interview data were examined for recurring themes related to self-awareness, emotional responses, and development over time.

Findings. During interviews and in module evaluations, students reported that the structured reflection process helped them clarify their learning goals and better understand their role within the team. They appreciated the long-term perspective on learning and the opportunity to track their development across multiple dimensions. Students did need support in developing reflective and metacognitive skills, especially early in the module. This highlights the need for scaffolding and guidance when implementing process-based learning approaches. Coaches found the framework helpful for providing targeted feedback and for facilitating meaningful conversations about learning and growth.

Conclusion. This intervention illustrates how a process-based learning approach can support the development of self-regulated learners in engineering education. By making learning visible, iterative, and reflective, students are empowered to take ownership of their growth and prepared for the complexities of professional practice.

Although the intervention was implemented in a small-scale module with 29 students, its structure is adaptable. The reflection cycles can be scaled by embedding them into existing module structures and by exploring the use of AI tools to support feedback and guidance at scale. The positive outcomes observed in ISBEP suggest that this approach holds promise for broader applications across curricula.

Case 2: Reflection as a tool for learning equity in engineering classrooms

Context. At Mbarara University of Science and Technology (MUST), a significant challenge emerged with the implementation of a revised engineering curriculum. A combined Digital Signal Processing (DSP) module now brings together third-year Biomedical Engineering (BME) students and third- and fourth-year Electrical and Electronic Engineering (EEE) students. Among these groups, only BME students have prior exposure to foundational technical concepts through a Signals and Systems module. In contrast, the EEE students encounter DSP content without any background. This misalignment has resulted in disparities in conceptual readiness,

limiting engagement, and creating frustration among students, particularly those who are seeing the material for the first time.

Intervention design. To address this challenge, a structured reflective learning intervention was introduced during the first semester of the 2024/2025 academic year, spanning four months. SRL development is driven by repeated reflection in an authentic engineering context. Therefore, participants were guided to maintain weekly learning journals in which they documented their evolving understanding, conceptual challenges, and personal strategies for bridging knowledge gaps. Typical prompts included:

1. What concept challenged you most this week?
2. What strategy did you use to address this challenge?
3. What will you try differently next week?

These journals were not assessed for correctness but were reviewed for reflection depth and consistency of engagement. This approach encouraged honest self-exploration and created space for students to think critically about their learning processes. The intervention intentionally targeted the SRL competencies of self-reflection, self-direction, and feedback literacy by encouraging students to plan learning actions, monitor conceptual understanding, and evaluate strategy effectiveness across weekly cycles. Early observations from journal analysis indicated that the reflective practice helped students navigate uneven prior knowledge, strengthened learner agency, and supported equitable participation across cohorts.

Implementation. Before implementation, informed consent was obtained from all students in the class. They were clearly informed that the intervention was intended to support their self-directed learning and metacognitive development, and that participation would not contribute to coursework marks or influence academic grading in any way. All 130 students voluntarily agreed to take part in the initiative.

Sample size. The intervention involved 130 engineering students across the BME and EEE programmes.

Data collection. Data consisted of weekly written learning journals, complemented by informal instructor observations and selected student excerpts that illustrated shifts in understanding and engagement. Journal prompts required students to articulate learning goals, identify conceptual misunderstandings, describe strategies used, and plan subsequent learning actions, thus generating evidence of SRL processes.

Data analysis. Journal entries were analysed using an inductive thematic analysis focusing on observable SRL behaviours, including goal setting, monitoring of understanding, help-seeking behaviour, strategy adaptation, and reflective evaluation. These indicators were interpreted through Zimmerman's cyclical SRL phases to identify evidence of forethought, performance monitoring, and self-reflection across the semester. Instructor observations were used to triangulate emerging patterns of engagement and learning agency. Reflections were compared across multiple journal submissions throughout the semester to identify recurring patterns in learning challenges, strategy use, and developmental growth.

Findings. Preliminary analysis of the journals shows that students began identifying their own learning gaps and experimenting with new strategies, like peer discussion and revisiting lecture notes. One student wrote, *"I thought I understood convolution, but writing it down made me realise I was confused. I had to go back and ask for help."* Another shared: *"Reflecting weekly helped me track my understanding. I no longer wait for the lecturer; I now try to figure things out myself."* These reflections suggest a shift toward greater metacognitive awareness and learning ownership, consistent with Zimmerman's model of SRL (Zimmerman, 2002). Across reflections, students increasingly demonstrated metacognitive awareness, proactive help-seeking, and deliberate strategy adaptation, indicating strengthening self-reflection and self-direction competencies over time.

These observations support broader findings in the literature. Turns et al. (2014) argue that reflection enables learners to assign meaning to their experiences and use that meaning to guide future actions. In our context, students revisited their learning journeys through the lens of their personal experiences, enabling them to make connections between new DSP content and previously held knowledge. This interpretive process mirrors what Cimer et al. (2013) describe as the power of reflection to improve not only content mastery, but also self-perception and motivation. Similarly, Kori et al. (2014) note that reflective writing can foster self-explanation and help students recognise inconsistencies in their understanding, which was evident in our students' journals.

The reflections also revealed how curriculum design influences learner identity and perceived belonging. Some EEE students expressed feelings of inadequacy due to their lack of foundational knowledge, while BME students described a sense of validation. However, over time, reflective practice appeared to level this disparity, enabling all students to identify individual learning goals, work toward them independently, and reflect on their progress. This suggests that reflection, as a context-sensitive pedagogical tool, can promote equity in learning outcomes across structurally diverse classrooms.

Conclusion. This case study illustrates how integrating reflective practice into a technically demanding module can support SRL, student agency, metacognitive growth, and learning equity in diverse classrooms. Ongoing analysis of student journals will deepen the understanding of reflective learning patterns, with future efforts focused on scaling this approach across modules and building faculty capacity. The intervention requires minimal additional resources and can be adapted by embedding short reflective prompts within existing coursework, making it suitable for large or resource-constrained engineering classrooms. The experiences in the case study affirm that meaningful pedagogical change can begin with simple, context-responsive practices that encourage students to think critically about how they learn.

Case 3: Longitudinal SRL intervention across the bachelor programme

Context. A three-year SRL intervention was developed for integration into the Engineering Technology bachelor curriculum at KU Leuven. It was piloted at Ghent

campus, embedded into the modules Dynamics and Energy and Vibrations and Waves in Year 1, Engineering and Economics and Statistics and Data Management in Year 2, and the Engineering Experience capstone in Year 3.

Intervention design. This intervention addressed the need for sustained SRL development and consisted of three overlapping stages aligned with study years. It begins with simplified direct SRL instruction based on Zimmerman's cyclical model, gradually building complexity over time. Materials were presented visually through infographics, followed by tests and practical applications. Assignment frequency was high at first and gradually reduced.

Year 1 focuses on supporting students' transition to higher education, aiming to raise awareness of their learning process and learner agency. SRL strategies, e.g., planning, learning strategies, and self-reflection, were directly introduced in relation to typical study tasks and mapped to Zimmerman's phases. Assignment design indirectly encouraged students to complete SRL cycles and to think ahead, fostering the continuous adaptation of their learning process.

Year 2 gradually shifted focus and incorporated both long- and short-term cycles. In the module in the first semester, students worked towards a self-chosen study goal, while short cycles on lab learning and individual deadline management characterised the second semester. These activities fostered autonomy and responsibility. In addition, SRL was introduced across different contexts to illustrate its relevance to academic, professional, and personal growth.

In the final year, students reflected on what type of engineer they wished to become and started working towards that vision, i.e., professional identity formation. Assignments were connected to compulsory industry visits and the campus job fair. The intervention ended with a look ahead, encouraging students to take ownership of their development through practicing SRL.

Implementation. The intervention was organised into semester-long learning modules on KU Leuven's Blackboard learning platform and came with a comprehensive manual, allowing instructors to easily copy and adapt materials to fit their needs. Student participation was compulsory, as the interventions were embedded in the regular curriculum.

In the first pilot phase, educational support was provided for setting up the semester-long learning modules. In a second pilot phase, the instructor implemented the semester-long learning modules independently.

Sample size. The longitudinal programme reached 280 engineering students across three-year levels, with full cohorts participating during the pilot phases.

Data collection. Data included module-SRL assignments, student reflections, planning tasks, and anonymised learning platform activity logs. Instructors also provided informal observations on student engagement and ease of implementation.

Data analysis. Quantitative data (e.g., task completion, timing, progression) were reviewed descriptively to track engagement patterns, while from a qualitative point of

view written reflections and instructor notes underwent a light thematic analysis to identify recurring SRL behaviours and shifts in autonomy over time.

Findings. Compulsory participation in the pilot project was initially met with student resistance, which gradually gave way to appreciation. Students reported reduced stress during examinations thanks to a study schedule they would not otherwise have made themselves. Students reported participation required about 15 minutes per week on average. In the second pilot phase, an instructor who implemented the intervention independently of the research team reported that the materials were easy to adapt to their student cohort and appreciated the low-effort setup and maintenance of the intervention.

Conclusion. This longitudinal intervention fostered SRL through various strategies tailored to engineering students, while remaining scalable and adaptable. Students gradually recognised its benefits, while instructors appreciated its straightforward implementation and follow-up.

4 Recommendations for implementation/learning

The SRL models, SRL competencies, SRL archetypes, and three case studies provide a foundation for implementing SRL interventions into engineering education in order to foster self-regulated learning among engineering students. To conclude, we offer recommendations for you building on this chapter and the personal experiences from the authors.

Design interventions on solid SRL foundations. Design SRL interventions that explicitly draw on well-established SRL models (e.g., Zimmerman's cyclical model, Boekaerts' dual processing model, and Hadwin's SSRL) and ensure that activities target core SRL competencies such as self-direction, self-reflection, autonomous motivation, and feedback literacy. Use the eight SRL archetypes for inspiration.

Make SRL competencies and processes explicit. Make sure that teachers have a clear view of the SRL competencies and processes that the intervention is targeting. Furthermore, decide when and how to provide students with an explicit view on these competencies and processes (e.g., direct or indirect instruction).

Build SRL into a variety of tasks, including authentic engineering tasks. Integrate planning, monitoring, and reflection into regular engineering modules, but also design projects, lab work, or problem-solving assignments. When SRL activities are embedded in a variety of tasks and contexts, students more readily see their relevance and apply them meaningfully, and transfer their SRL skills to new tasks.

Start small and build incrementally. Practitioners do not need to immediately redesign entire programmes to support SRL. Begin with one intervention, such as a short reflection cycle, a self-assessment rubric, or structured peer feedback, and expand gradually building on the earlier experiences.

Aim for a longitudinal approach. A longitudinal approach helps students progress from guided practice in the first year to greater independence in later years. Spread SRL opportunities across different modules and contexts so students can refine

competencies as tasks become more complex and are supported in developing long-term SRL competencies.

Offer regular opportunities for structured reflection. Use recurring reflection cycles, learning journals, or short check-ins that prompt students to articulate their learning goals, analyse their performance, and plan next steps. Scaffolding should be strongest early in the module or programme and gradually decrease as students gain confidence.

Use feedback strategically to develop feedback literacy. Combine external feedback (from instructors, peers, or learning analytics) with activities that require students to interpret and act on it. Encourage learners to compare their own self-assessment with external perspectives so they can calibrate their judgements and refine their strategies.

Leverage peer interaction to support co- and socially shared regulation. Integrate peer support, team-based reflection, or collaborative goal-setting. Peers can trigger productive SRL behaviours, and offer motivational support, especially in project-based or interdisciplinary environments.

Use technology intentionally when designing and executing interventions. Technology can be the teacher's assistant when developing and executing SRL interventions. Learning analytics dashboards, study planners, automated feedback systems, AI tutors, etcetera can help students track their behaviour, set realistic goals, and make informed adjustments. Technology can moreover support teachers to cover larger student audiences. Make sure to combine technological tools with human guidance to help students interpret what the data means, ensure motivation, and create a sense of belonging, thus ensuring socially shared regulation.

Integrate SRL assessment to reinforce learning. Providing students feedback on their SRL development requires assessment of SRL. Moreover, while formative feedback is powerful, students are not only driven by intrinsic motivation, but also summative assessment. Appropriate assessment strategies and instruments for SRL should be developed. Combine easily accessible assessment tools such as self-assessment rubrics, progress checklists, or short reflective prompts, that help students evaluate their own learning processes; with targeted summative assessment preferably connecting SRL to authentic learning tasks.

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AI statement

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2.14

Adaptability in Engineering Education

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Adaptability is a core professional capability for engineers working in complex, rapidly changing environments. This chapter defines adaptability as the capacity to anticipate and respond to change by adjusting knowledge, skills, behaviours, and attitudes in ways that sustain performance and long-term growth. Drawing on psychology, career development, and engineering education, it frames adaptability as a multidimensional, learnable capacity encompassing cognitive flexibility, emotional regulation, motivation, collaboration, sociotechnical awareness, and reflective practice. For engineering educators, the focus is practical. The chapter translates theory into design principles and worked examples drawn from authentic teaching contexts, demonstrating how adaptability can be intentionally cultivated through project-based learning, teamwork, intercultural engagement, mentoring, and structured reflection. It also provides guidance on recognising adaptive processes in student work, including observable indicators, artefacts, and formative cues that make adaptability visible without reducing it to a single metric. By making adaptability explicit, visible, and equitably supported, you can help students develop the judgement, resilience, and professional agency needed to navigate uncertainty and lead change throughout their careers.

1 What is adaptability?

Adaptability has been defined across multiple fields, but this chapter begins with SEFI's framing: "*a learner's adaptability involves identifying qualities that are critical for future performance and being both willing and able to make personal changes in a proactive way*" (Hall & Chandler, 2005, p. 163). This definition emphasises two essentials: learners must recognise what is changing and why it matters, and they must be both willing and able to adjust their skills, attitudes, and behaviours accordingly. Adaptability is therefore not passive reaction, but adjustment grounded in initiative.

The SEFI (2025) Skills Position Paper situates adaptability within professional commitment and lifelong learning, alongside resilience and reflective practice. In this sense, it is not an isolated trait but part of how engineering education prepares students to navigate complexity and change. To clarify what adaptability entails in practice, it is helpful to consider three complementary perspectives.

1.1 Conceptual foundations

Workplace psychology frames adaptability as the ability to adjust thinking and behaviour in response to new, changing, or uncertain demands (Martin & Rubin, 1995; VandenBos, 2007). Pulakos et al. (2000, 2006) describe adaptive performance as observable behaviours such as solving ill-defined problems, managing stress, learning new tasks, and working effectively with diverse others, making adaptability visible in action. Ployhart and Bliese's (2006) Individual Adaptability (I-ADAPT) theory conceptualises adaptability as a multidimensional construct encompassing cognitive, interpersonal, cultural, physical, and learning-related forms of adaptation. It emphasises that successful adaptation depends not only on ability but also on motivation and disposition.

Career development research approaches adaptability through the lens of transitions. Career Construction Theory defines career adaptability as the psychosocial resources individuals use to navigate change, summarized in the four Cs (Savickas, 2005; Savickas & Porfeli, 2012): concern (future orientation and planning), control (agency and responsibility), curiosity (exploring alternatives), and confidence (belief in one's ability to solve problems). These resources are learnable and predictive of how individuals manage uncertainty, decision points, and setbacks. Like workplace psychology, this perspective shifts adaptability from a vague personality trait to a structured set of developable capacities.

Engineering adds further nuance. Because engineering work is inherently dynamic, adaptability appears in reframing problems as conditions shift, managing ambiguity and stress, collaborating across differences, and continuing to learn as tools and technologies evolve (Brunhaver et al., 2024; Sajadi, 2022). The concept of adaptive expertise clarifies the balance between efficient application of knowledge and innovation in unfamiliar situations (Hatano & Inagaki, 1986). Design adaptability similarly emphasises anticipating change and building flexibility into systems from the

outset (Fletcher et al., 2010). In engineering, adaptability is therefore both reactive (responding effectively) and proactive (designing for change).

Bringing these perspectives together, adaptability in engineering education can be defined as the capacity to anticipate and respond to personal, technical, organisational, or cultural change by adjusting knowledge, skills, and behaviours in ways that sustain performance, learning, and professional growth. It draws on multiple forms of reasoning and judgement, is enacted individually and collaboratively, and can be developed intentionally through educational experience. Rather than a fixed trait, adaptability is a professional capacity that can be deliberately cultivated.

2 Why adaptability matters

Adaptability matters because engineering is practised in dynamic and evolving conditions. Requirements shift, constraints emerge unexpectedly, and collaboration across disciplines and cultures is routine. Thriving in such environments requires more than technical competence; it calls for judgement, flexibility, and the capacity to adjust when circumstances change. Professional bodies have consistently identified adaptability as central to engineering formation. The Engineer of 2020 report (NAE, 2004) and SEFI's Skills Position Paper (2025) position it alongside resilience, reflection, and lifelong learning as foundational to professional identity rather than as a transient workplace trend. This section outlines four reasons why adaptability is essential in contemporary engineering education.

2.1 Professional and workforce context

Engineering now operates within rapidly shifting technological, environmental, and geopolitical conditions. Automation, climate transitions, demographic shifts, and global interdependence continually reshape professional practice and redefine what expertise looks like in context. Roles evolve as quickly as the tools and systems that engineers design. Employers therefore increasingly seek graduates who can make decisions under pressure, collaborate across boundaries, and continue learning as industries evolve (World Economic Forum, 2025).

In volatile contexts, organisations that can pivot and reconfigure are more likely to outperform those built on rigid models (Bennett & Lemoine, 2014). For engineers, this means technical expertise must be accompanied by the ability to integrate new information, reframe problems, and adjust strategies in real time. At the workforce level, adaptability supports employability, organisational resilience, and innovation.

2.2 Engineering practice under uncertainty

Engineering practice routinely involves ambiguity and constraint. Client priorities shift mid-project, testing reveals unanticipated failure modes, and regulatory or budget pressures compel redesign. Research on adaptive performance identifies behaviours such as managing stress, solving ill-defined problems, learning new tasks, and collaborating across difference as central to effective performance (Pulakos et al., 2000, 2006). These behaviours are visible in everyday engineering work: revising

assumptions after a failed prototype, adjusting designs in response to stakeholder input, or redistributing team roles when expertise gaps emerge.

Studies of early-career engineers reinforce this pattern. Preparedness often means not having immediate answers but knowing how to proceed productively in unfamiliar situations (Brunhaver et al., 2024; Deters et al., 2024). In practice, adaptability is frequently expressed as resourcefulness and composure under pressure rather than dramatic innovation. For you as an educator, this matters because the conditions that define professional competence, including ambiguity, shifting constraints, and incomplete information, cannot be removed from engineering practice and must instead be navigated.

2.3 Lifelong learning and professional growth

Beyond responding to immediate workplace demands, adaptability sustains long-term professional growth. While specific technical knowledge may become obsolete, the capacity to extend, reinterpret, and transfer knowledge across contexts endures. The distinction between routine and adaptive expertise illustrates this balance (Hatano & Inagaki, 1986). Routine expertise supports efficient performance in stable situations; adaptive expertise supports innovation and learning in unfamiliar situations.

Professional growth depends on developing the ability to learn from disruption rather than merely react to it. Research on growth-oriented beliefs shows that individuals who treat ability as developable are more likely to persist and refine their competence over time (Yeager & Dweck, 2012). Adaptability, in this sense, underpins lifelong development by enabling engineers to expand their professional repertoire rather than simply maintain it.

2.4 Equity and inclusion

Adaptability has important implications for equity. Students do not encounter engineering from equal starting points. First-generation students, women, students of colour, international students, and others navigating systemic barriers often experience greater instability within educational systems. In such contexts, adaptability can function as a protective capacity. Career adaptability research highlights the four resources — concern, control, curiosity, and confidence — that support agency in the face of constraint (Savickas & Porfeli, 2012). Growth-oriented classroom climates have likewise been shown to strengthen adaptive responses and resilience, particularly in institutions serving historically underrepresented populations (Verdín & Pérez Leon, 2025).

At the same time, adaptability should not be framed as an individual responsibility to compensate for systemic inequities. Educational environments must be designed to support adaptive growth equitably. When supported intentionally, adaptability strengthens persistence, belonging, and long-term professional mobility.

2.5 Why this matters for engineering education

In summary, adaptability matters because it enables engineers to function effectively amid evolving conditions, supports innovation in dynamic technological and

organisational contexts, sustains lifelong learning, and contributes to persistence across diverse pathways. Like technical competence, it requires deliberate cultivation. When left implicit, its development is uneven; when made visible, it strengthens both professional formation and educational equity.

3 Developing adaptability in engineering education

Adaptability develops when students must exercise judgement rather than follow routine procedures. Because it spans multiple aspects of learning and professional development, it cannot be cultivated through a single intervention. Research suggests that adaptive capacity strengthens when learners must interpret evolving conditions instead of applying predetermined responses (Hatano & Inagaki, 1986; Pulakos et al., 2000). The domains that follow represent complementary contexts in which adaptability can be intentionally developed.

To make these domains concrete, this section includes practice-based examples drawn from the author's teaching and programme design experience at Arizona State University, USA, situated within specific modules or programmes. While the examples reflect a single institutional context, they are intended to illustrate instructional approaches that can be adapted across engineering education settings. Each outlines the educational context, targeted dimension of adaptability, activity structure, evidence generated, and observable indicators of adaptive development. Together, they illustrate how adaptability can be intentionally designed for, made visible in student work, and supported across multiple stages of engineering education.

3.1 *Experiential learning and project-based learning*

Experiential and project-based environments foster cognitive adaptability by embedding complexity directly into technical problem solving. In experiential learning contexts, students engage with authentic tasks that require applying, testing, and revising knowledge in response to feedback from real or simulated situations. Project-based learning similarly situates students within sustained, open-ended challenges. When students confront shifting requirements, incomplete data, or ill-structured problems, they must reassess assumptions and refine strategies rather than rely on fixed solutions. Research on project-based learning shows that open-ended tasks increase tolerance for ambiguity and support iterative reasoning (Akinci-Ceylan et al., 2018; Hertz, 2018), while adaptive performance research highlights the value of practising responses to changing conditions (Pulakos et al., 2006).

Early exposure to open-ended design and problem-framing tasks helps students recognise iteration as a normal feature of engineering practice. As complexity increases, capstone and industry-based projects require reallocating resources, revising timelines, and redesigning in response to stakeholder feedback, particularly when constraints shift after substantial investment in an initial solution, as illustrated in Example 1. Experiential formats such as simulations and crisis scenarios further intensify these demands by introducing time pressure and competing constraints (Andrijcic, 2016; Audunsson et al., 2018). In this domain, adaptability becomes visible

when students refine models, abandon ineffective approaches, and improve solutions based on new evidence.

Example 1. Mid-semester design constraint shift in capstone design

In a senior engineering capstone design module involving industry-sponsored teams of four to six students, a mid-semester constraint shift was introduced to develop both cognitive and technical adaptability under changing conditions. During week 6 of the 15-week semester, after completing a preliminary design review with their instructor, classmates, and industry sponsors, they received a formal "client update" memo introducing two new constraints: a 20% budget reduction and an additional regulatory requirement related to safety or environmental compliance, depending on the project focus. Teams were given ten days to submit a revised design brief (maximum eight pages), a structured change log with invalidated assumptions, alternatives considered, and resulting trade-offs documented, and a 600-word team reflection explaining how their reasoning evolved in response to the new conditions. Assessment prioritised the quality of revision and justification rather than improvement of the final design alone.

Annotated design revisions, structured change logs, trade-off matrices, and team reflections provided evidence of how students responded to disruption and uncertainty. Students demonstrated adaptive development when they identified flawed or outdated assumptions, abandoned sunk costs, articulated trade-offs transparently, and clearly linked revised constraints to redesign decisions. Because students often treat early design work as something to defend, introducing disruption after substantial investment created authentic cognitive tension similar to professional engineering practice. In this setting, adaptability became visible not only in the revised product but also in how students reframed their reasoning. One implementation insight was that students initially resisted abandoning prior work; explicitly normalising iteration reduced defensiveness and encouraged deeper analysis. Requiring a dedicated "Invalidated Assumptions" section also strengthened the quality of student reflection and justification.

3.2 Teamwork and peer learning

Adaptability in engineering is rarely individual. Team settings foreground interpersonal adaptability: the ability to adjust communication, coordination, and role distribution in response to others. Professional practice requires integrating of diverse expertise and managing disagreement productively (Boelt et al., 2023; Pulakos et al., 2000). Industry-sponsored projects similarly show that students rely on peer knowledge sharing and mentorship when navigating ambiguous situations (Misra et al., 2023).

Collaborative structures involving shared decision making, rotating leadership, and structured feedback create conditions for interpersonal adjustment. In these contexts, adaptability is evident when teams renegotiate direction, redistribute responsibility, and maintain cohesion despite competing perspectives, as demonstrated in Example 2. Over time, such experiences reinforce adaptability as a shared professional

responsibility shaped through interaction and negotiation rather than an individual attribute.

Example 2. Role reversal and conflict analysis in a design module

To disrupt routine team dynamics and encourage perspective-taking, students in a Year 2 engineering design module participated in a structured role-rotation activity focused on developing interpersonal and collaborative adaptability. Conducted at two checkpoints during the semester (weeks 4 and 9), the activity required each student to temporarily assume a role they had not previously held (e.g., a technical lead became a stakeholder liaison). Teams were also presented with a short tension scenario, such as conflicting performance priorities or deadline compression. They then submitted a 2-3-page decision log documenting points of disagreement, alternatives considered, and how resolution was reached, along with a 300-500-word individual reflection analysing how their reasoning or communication shifted in the new role.

Student responses reflected adaptability when participants adopted alternative viewpoints, adjusted communication strategies, redistributed responsibility without escalation, and explicitly documented negotiated decisions. The activity generated role documentation, decision logs, and individual reflections that made collaborative adjustment processes visible. Disrupting established team hierarchies destabilised routine interaction patterns and required students to reconsider how they justified decisions and coordinated across difference. In this context, adaptability emerged through collaborative recalibration rather than technical revision alone. A key implementation insight was that students tended to avoid meaningful disagreement without structured prompts; explicit tension scenarios therefore deepened engagement and strengthened analysis. Requiring individual reflection also increased accountability and reduced the likelihood that dominant voices would shape the team narrative.

3.3 Cultural and global learning

Engineering practice increasingly spans geographic, disciplinary, and value boundaries. Intercultural adaptability involves reconsidering assumptions, communication styles, and evaluative criteria across difference. Studies of international collaboration show that students build adaptive capacity when navigating unfamiliar norms, time zones, and stakeholder expectations (Lord et al., 2013; Mthombeni et al., 2024). Integrating sociotechnical reasoning, i.e., balancing technical feasibility with ethical and social considerations, likewise requires perspective shifting (Czerwionka et al., 2025).

In this domain, adaptability is visible when students modify communication strategies, interrogate implicit values, and incorporate diverse viewpoints into technical decisions, a process reflected in Example 3 through students' reconsideration of context-dependent engineering priorities. Rather than treating difference as an obstacle, they

learn to treat it as a prompt for reassessment, an increasingly central capability in global and interdisciplinary engineering contexts.

Example 3. Cross-case structural analysis across contexts

Students in a Year 2 engineering mechanics module enrolling approximately 60 students compared two structurally similar bridge systems situated in contrasting sociotechnical contexts to develop intercultural and sociotechnical adaptability. Conducted mid-semester during the application of structural analysis to real systems, the activity contrasted an urban US pedestrian bridge prioritising minimal deflection and long service life with a rural, flood-prone river crossing prioritising local materials, repairability, and community labour. After completing a simplified structural analysis, students wrote an 800-1000-word memo explaining how a design optimised for one context would need to adapt for the other, and vice versa. They were required to identify context-dependent assumptions, shifts in performance criteria, and implications for material choice and maintenance.

The resulting comparative modelling summaries, lists of context-dependent assumptions, and cross-case transfer memos revealed how students reconsidered what counted as an 'optimal' design under changing stakeholder priorities. Adaptive development became visible when students revised modelling assumptions in response to economic or cultural conditions and incorporated maintenance capacity and material access into their reasoning. Because mechanics problems are often treated as context-neutral, the activity highlighted the socially embedded nature of engineering judgement and encouraged students to recalibrate definitions of success rather than simply recalculate technical solutions. One design feature that strengthened the activity was the inclusion of a clearly labelled "Context-Driven Assumptions" section, which deepened analysis beyond simple cost comparison. Requiring individual submission prior to discussion also strengthened the quality of classroom dialogue.

3.4 Mindset and reflective practices

External disruption alone does not guarantee development. Psychological adaptability concerns how students interpret and regulate their responses to challenge. Growth mindset research shows that viewing ability as developable strengthens persistence under difficulty (Yeager & Dweck, 2012). Career adaptability research similarly highlights the importance of concern, control, curiosity, and confidence in navigating transitions (Savickas & Porfeli, 2012).

Educational practices such as iterative design, structured debriefs, reflective documentation, and low-stakes reframing exercises support this internal dimension, while tools including learning journals and online portfolios help students consolidate insight from experience. Example 4 highlights how recurring reflective checkpoints can help students recognise patterns in their responses to challenge and develop more intentional adaptation strategies over time. Here, adaptability is not simply in

behavioural change, but in how students integrate challenges into their emerging professional identity.

Example 4. Adaptive reflection portfolio checkpoint

Across three checkpoints in a Year 1 engineering student success seminar enrolling approximately 20 students, learners engaged in a structured reflection process designed to support psychological and transitional adaptability. At weeks 4, 8, and 12, students wrote a 500-word reflection describing a specific academic challenge, their initial response, a strategy they adjusted or could adjust, and resources they used or avoided. At the final checkpoint, students reviewed earlier entries to identify patterns in how they responded to difficulty and developed a short adaptation plan for the following semester. The four Cs framework of concern, control, curiosity, and confidence was discussed explicitly to guide reflection and interpretation.

Timestamped reflection entries, pattern analyses, and forward-looking adaptation plans provided evidence of how students interpreted and responded to challenge over time. Students demonstrated adaptive development when they shifted from fixed-ability language toward strategy-focused analysis, engaged more readily in help-seeking behaviour, and transferred strategies across modules. The activity was particularly effective because early setbacks can threaten students' sense of belonging; by emphasising strategy adjustment rather than flawless performance, the seminar reframed difficulty as a normal part of transition and positioned adaptability as an identity-level skill. Providing anonymized model reflections improved analytical depth, while short, recurring entries supported stronger metacognitive growth than a single end-of-term reflection. Using low-stakes, completion-based grading also encouraged more candid reflection and reduced the tendency for students to tailor responses to perceived grading expectations.

3.5 Structured modules and transitional support

While adaptability often emerges within embedded learning experiences, it can also be cultivated deliberately through structured modules and mentoring programmes. Targeted interventions are particularly effective at strengthening transitional adaptability, the capacity to anticipate and navigate periods of change. Research suggests that these structured supports can strengthen the planning behaviours, agency, and confidence that underpin adaptive development (Cheung & Jin, 2016; Green et al., 2019).

Programmes may draw on frameworks such as the four Cs model of career adaptability (Savickas & Porfeli, 2012), while integrating reflective practice, goal setting, scenario planning, or resilience training. They are especially valuable at key transition points, such as the transition from secondary education to university, pre-capstone preparation, entry to professional practice, or the beginning of graduate study, when expectations shift and ambiguity increases (Koen et al., 2012). Example 5 demonstrates how structured peer mentoring can support students in navigating uncertainty, recalibrating expectations, and developing confidence during periods of

transition. Even brief interventions can increase perceived adaptability, while sustained engagement tends to yield more durable effects (Janeiro, 2014). In this context, adaptability involves preparing for change as much as responding to it.

Example 5. Peer mentorship for doctoral transition

Because doctoral study is characterised by prolonged ambiguity and evolving expectations, incoming students in an Engineering Education doctoral programme were paired with advanced peer mentors to support the development of transitional and professional identity adaptability. Conducted throughout the first academic year, the programme unfolded in three stages. During the first month, students mapped anticipated and unanticipated uncertainties, including evolving adviser expectations and research ambiguity. In the second stage (months 2-4), mentors facilitated structured discussions focused on recalibration after proposal rejection, shifts in research direction, or teaching missteps. In the final stage, students and mentors co-developed a two-page plan for their adaptive development, outlining strategies for navigating evolving expectations. Guided prompts were used throughout to anchor discussion and reflection.

Transition mapping worksheets, mentor discussion summaries, and adaptive development plans documented how students interpreted and navigated uncertainty over time. Adaptive development became visible when students recognised that research directions evolve, proactively clarified expectations, responded constructively to critique, and demonstrated increased comfort with intellectual uncertainty. Peer mentorship was especially valuable because it normalised recalibration as part of scholarly practice rather than as evidence of failure, making adaptability visible as part of professional formation. In practice, structured prompts produced deeper conversations than informal mentor pairings alone, while early-semester implementation proved critical, because waiting until challenges escalated reduced effectiveness. Clear mentor role definitions also helped maintain the relationship as developmental rather than supervisory.

3.6 Cross-cutting developmental patterns

Although the domains above emphasise different aspects of adaptability, they share a common developmental structure. In each case, students encounter disruption, interpret what it means, and refine their response. The disruption may be technical (a failed design assumption), interpersonal (team disagreement), sociotechnical (competing stakeholder priorities), or transitional (shifting expectations). What matters is how students process and respond to it.

Across contexts, adaptability develops through repeated cycles of (1) exposure to change or ambiguity; (2) interpretation of its implications; (3) adjustment of reasoning, strategy, or behaviour; and (4) consolidation through reflection or feedback. When you design for these cycles intentionally, adaptability becomes visible and developable rather than incidental. Early experiences often focus on cognitive and psychological adjustment, while later experiences integrate interpersonal,

sociotechnical, and professional identity dimensions. Over time, students move from reacting to change toward anticipating and managing it.

The sections above introduced these dimensions separately. Table 2.14.1 consolidates them into a single practitioner reference to support recognition and formative feedback in your own context.

Table 2.14.1: Observable indicators of adaptability in student work

<i>Dimension</i>	<i>Observable behaviours</i>	<i>Artefacts</i>	<i>Formative cues</i>
Cognitive/technical	Revises assumptions; reframes problems; compares alternatives	Design revisions; change logs; modelling memos	Identifies invalidated assumptions; uses conditional reasoning; justifies trade-offs
Interpersonal/collaborative	Renegotiates roles; integrates perspectives; adjusts communication	Team decision records; peer feedback; conflict reflections	Documents disagreement and resolution; shows perspective-taking; redistributes responsibility productively
Sociotechnical/intercultural	Reconsiders performance criteria across contexts; adapts priorities	Stakeholder analyses; comparative case memos	Recognises context-dependence of 'optimal'; integrates social and technical constraints
Psychological/motivational	Adjusts learning strategies; seeks feedback; persists under uncertainty	Reflection entries; adaptation plans	Moves from fixed-ability language to strategy analysis; articulates transfer to future situations
Transitional/professional	Clarifies expectations; recalibrates goals after critique	Development plans; revision narratives	Interprets feedback constructively; plans proactively for uncertainty

These indicators function as formative reference points rather than grading criteria. The emphasis is less on the product itself and more on the reasoning and adjustment

it makes visible. When reviewing a change log or reflection, pay attention to how students explain their decisions, recalibrate strategies, and connect present learning to future action. Making these expectations explicit helps students understand that adaptability is demonstrated through process, not just outcome. For more formal assessment approaches, refer to Part 3 chapters on peer assessment, self-assessment, rubrics, observations, portfolios, and inclusive and ethical assessment.

4 Designing for adaptability

Because adaptability develops through cycles of adjustment and refinement, it must be designed intentionally. While some students acquire adaptive habits through experience alone, most benefit from explicit guidance, feedback, and support. Research shows that adaptive capacity strengthens when challenge is paired with structured feedback and reflection (National Academies of Sciences, Engineering, and Medicine, 2018; Pulakos et al., 2006). The principles below translate the developmental patterns described in Section 3 into practical decisions you can make in your curriculum.

4.1 Name adaptability explicitly

Students are unlikely to prioritise adaptability unless it is clearly identified. Define it explicitly in your course materials. Include it in learning outcomes, project briefs, and assessment criteria. Describe what it looks like in your discipline; for example, revising assumptions, responding to new constraints, managing ambiguity, or adjusting roles within a team.

Established frameworks such as adaptive performance (Pulakos et al., 2006) can provide students with shared language and structure. When adaptability appears in grading rubrics, feedback conversations, and milestone reviews, it becomes part of the evaluative architecture of the module rather than an implicit expectation. The goal is alignment, ensuring that goals, activities, and assessment consistently reinforce adaptability as a professional capability.

4.2 Design for productive complexity

Adaptability grows through meaningful challenge, but unmanaged challenge can erode confidence. Learning experiences should introduce complexity progressively rather than all at once. Early activities might involve open-ended problem framing or low-stakes ambiguity. As students gain experience, constraints can become tighter, timelines shorter, and stakeholder demands more varied, culminating in higher-pressure capstone or industry contexts.

Research on adaptive expertise indicates that novelty supports growth only when learners have sufficient scaffolding to interpret and respond constructively (Hatano & Inagaki, 1986). Mentoring, modelling, and structured opportunities to reconsider approaches are essential supports (Brunhaver et al., 2024; Misra et al., 2023). The aim is not to eliminate complexity, but to calibrate it so students develop confidence in engaging with evolving conditions rather than withdrawing from them.

4.3 Embed reflective processing

Exposure to challenge alone does not produce adaptability; interpretation does. Students need structured opportunities to examine how they responded to disruption. After design revisions, team conflict, or unexpected constraints, require brief analytical reflections focused on reasoning and adjustment.

Short, recurring reflection cycles are often more effective than a single end-of-term reflection. Iteration logs, post-milestone debriefs, or targeted peer discussions help students consolidate what they learned from disruption (Liu & Wan, 2024). Reflection should focus on patterns, asking how reasoning evolved, what prompted the shift, and what lessons will inform future action. When processing is deliberate and repeated, adaptability becomes transferable rather than context-bound.

4.4 Structure intercultural engagement

Intercultural adaptability does not emerge automatically from diverse groupings or international exposure. Research suggests that intercultural development depends on intentional framing, guided interaction, and structured processing (Lord et al., 2013; Mthombeni et al., 2024). Designing for adaptability in this domain requires clarity about purpose. Students should understand that navigating differences in communication styles, assumptions, and values is an expected dimension of professional competence.

Structured debriefing is essential. After intercultural interactions, prompt students to analyse how differing perspectives influenced their decisions, where misunderstandings arose, and how they adjusted their approach. Make this analysis visible in project documentation or assessment criteria. Without guided interpretation, intercultural encounters may reinforce existing habits rather than broaden them (Downey et al., 2006). When examined deliberately, intercultural engagement fosters sustained perspective-taking rather than surface coordination.

4.5 Reinforce through assessment and feedback

If adaptability is never acknowledged in assessment, students may perceive it as peripheral. What is evaluated shapes what students prioritise. Make adaptive processes visible alongside technical outcomes by clarifying that responsiveness, revision, and thoughtful adjustment are part of professional performance. This does not require complex measurement systems, but rather transparency about what is being evaluated and why it matters.

Mechanisms such as design revision logs, team decision records, or brief self-assessments can document adaptive thinking. Feedback should address not only final products but also how reasoning, roles, or strategies evolved. Timely, specific feedback strengthens adjustment behaviours (Pulakos et al., 2006), and structured reflection paired with feedback enhances transfer (Liu & Wan, 2024).

4.6 *Design equitable access to challenge and support*

Promoting equity requires that opportunities to develop adaptability be distributed intentionally across the student cohort. If demanding tasks are unevenly experienced, or if access to guidance depends on informal networks, adaptive growth may concentrate among those who are already comfortable navigating uncertainty. Research on career adaptability suggests that students benefit most when opportunities to exercise agency are paired with structural guidance (Savickas & Porfeli, 2012).

To advance equity in practice, ensure that all students engage with substantive complexity and that support mechanisms are predictable and accessible. Make revision pathways transparent, embed regular feedback cycles, and provide mentoring structures that are visible rather than optional (Tomlinson, 2017). When access to both challenge and support is consistent, adaptability becomes a shared curricular outcome rather than an unevenly acquired advantage.

4.7 *Integrating the design principles*

Adaptability becomes a deliberate outcome of engineering education when you design for it intentionally. It does not emerge reliably as a by-product of project work or collaboration alone. It develops when it is named explicitly, scaffolded progressively, reinforced through feedback, and supported equitably. The six principles outlined above — making adaptability explicit, sequencing complexity, embedding reflection, structuring intercultural engagement, reinforcing through assessment, and ensuring equitable access — are most powerful when they operate together. Introducing ambiguity without reflection may overwhelm students. Reflection without authentic challenges produces limited growth. Assessment without clarity may obscure what you intend students to develop. When aligned, these elements transform adaptability from an implicit expectation into a coherent curricular one.

In practice, integrating these principles means designing environments in which adjustment is visible, expected, and examined. In this way, students revise rather than merely complete. They explain how their reasoning changed, not just what they produced. They encounter complexity that stretches them, but with sufficient support to interpret and respond constructively. Over time, they begin to anticipate change rather than simply react to it. A simple implementation check can help ensure alignment (Table 2.14.2). When these conditions are in place, adaptability becomes part of professional formation rather than a hidden or unevenly acquired advantage. Students leave not only with technical competence, but with judgement and confidence to navigate evolving conditions throughout their careers.

Table 2.14.2: Implementation checklist for designing for adaptability

-
- Have I named adaptability explicitly in learning outcomes, assessment criteria, or project briefs?
 - Does the module include structured moments of uncertainty, ambiguity, or constraint shift?
 - Are students required to make their reasoning visible by documenting how and why it changes?
 - Is feedback directed at adaptive processes (revision, recalibration, strategy shifts) as well as final products?
 - Are opportunities for challenge and support distributed equitably across the cohort?
-

4.8 Resources and further reading

In addition to the literature listed in this chapter, I would recommend Hatono and Inagaki (1986), Plyhart and Bliese (2006), Pulakos et al. (2006) and the work by the National Academies of Sciences, Engineering, and Medicine on adaptability of the US engineering and technical workforce (2018) and the Engineer 2020: visions of engineering in the new century by the National Academy of Engineering (2004).

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AI statement

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Cultivating Student Resilience: Individual Capacity and Institutional Responsibility

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Future engineers face growing complexity and uncertainty when addressing global crises and societal challenges, including climate and technological change. This necessitates equipping engineering students with the ability to navigate complexity and adapt to career transitions, leading to an increased emphasis on resilience within degree programmes. Resilience, broadly defined as the ability to adapt to, and learn from, adverse situations, has become a focal point in policies and a desirable attribute for graduates. In this chapter, we define resilience and discuss reasons why its significance is growing within engineering education. Following this, we present ways resilience can be included within engineering education, notably through the use of problem and challenge-based approaches, design thinking, and teamwork. We conclude by cautioning against uncritically embedding 'resilience' into engineering modules. Instead, we emphasise the need for contextual and intersectional approaches that account for the systemic factors and structural barriers that differentially impact student experiences and mental health.

1 Definition

1.1 Conceptualisation across disciplines

'Resilience' is utilised across disciplines and associated with several definitions. Within engineering education, it has been linked to students (as a personal attribute) and systems (Winkens & Leicht-Scholten, 2023), with the concept of 'resilience engineering' (Hollnagel et al., 2006) used in infrastructure design in relation to how systems perform under stress.

This chapter focuses on individual resilience. We draw on psychology, where definitions of resilience typically include reference to two concepts: adversity, and positive adaptation (Luthar et al., 2000). The American Psychological Association (2018a) defines it as "*the process and outcome of successfully adapting to difficult or challenging life experiences, especially through mental, emotional, and behavioral flexibility and adjustment to external and internal demands*".

Shared understanding of resilience involves establishing conceptual clarity and consensus regarding these elements. For example, adverse conditions range from single experiences, such as major disasters, to multiple minor events, with resilience mechanisms varying by severity. Importantly, these conditions are not exclusively negative, and it is argued that positive life events such as job promotions also require adaptive responses and thus engage resilience processes (Fletcher & Sarkar, 2013).

Similarly, indicators of positive adaptation vary across context. Luthar et al. (2000) caution against expecting individuals to exhibit adjustment across conceptually unrelated domains, but that uniformity is expected across similar domains or contexts. In practice, this means that students who appear to be resilient based on academic grades should also demonstrate constructive academic behaviours. However, such indicators are often grounded in Western psychological frameworks that prioritise individual achievement and interpersonal functioning, potentially overlooking the influence of sociocultural contexts (Ungar, 2011).

Given this variability, determining what counts as 'positive adaptation' is not straightforward. It requires careful consideration of which outcomes are most relevant in a given context, as well as the level of functioning (whether 'adequate' or 'exceptional') that constitutes resilience. Luthar et al. (2000) suggest that these decisions be guided by the nature and severity of the risk, and the extent to which adverse events (e.g., failing an exam) threaten key outcomes (e.g., progression). Finally, applying resilience to specific contexts requires defining an appropriate reference point for recovery or growth. In engineering education, resilience has been conceptualised as an internal competency, drawing on O'Leary and Ickovics (1995), who identify four possible responses to adversity: thriving, recovery, survival, and succumbing.

1.2 Frameworks and models

Resilience has been studied extensively in psychology. While some view it as a trait, "*an enduring personality characteristic that describes or determines an individual's*

behavior across a range of situations”(American Psychological Association, 2018b), it is more commonly conceptualised as a dynamic process between individuals and their context and involves utilising protective factors to mitigate adverse effects of stressors (Masten, 2019).

Several frameworks and models can be used to inform resilience-based education. Martin and Marsh’s (2006) five Cs of academic resilience and Ginsburg’s (2014) seven Cs of resilience view it as an individual trait. Both models include the ability to control outcomes, confidence in one’s own ability, and coping with stress or composure. In addition, Ginsburg’s model incorporates competence required to handle situations effectively, connection with family and friends, character values, and contributing to the community and sense of purpose, with Martin and Marsh’s model including coordination (planning) and commitment (persistence).

In comparison, several frameworks emphasise the role of broader systems. Those most relevant to education include the Building Assets, Reducing Risks (BARR) model (Jerabek et al., 2023), which adopts a strengths-based approach, and involves identifying and nurturing students’ internal assets through intentionally designed supportive environments. The Academic Resilience Model (de Oliviero Durso et al., 2021) offers a multi-layered view, encompassing: individual factors, such as motivation and prior experiences; academic systems, including peers and assessment; and external influences, for example health, work, and family. Ungar (2011) views resilience as shaped by access to resources, community support, and culturally meaningful interactions, and Ebersöhn (2019) introduces the concept of flocking, rooted in Southern African Ubuntu philosophy, which frames resilience as a collective process.

Within engineering education, Bronfenbrenner’s (1979) bioecological systems theory has been applied to map stress cultures and identify support needs across system levels (e.g., Jensen et al., 2023), offering a framework which can be used to understand resilience and its development (see Table 2.16.1).

Such models are useful in designing resilience-based interventions. Drawing upon the work of Kalisch et al. (2024), Schäfer et al. (2024) describe a need to select context-sensitive strategies and allow flexibility in matching coping resources and resilience factors in response to situational demands. This highlights the need to identify the characteristics of a situation and select appropriate strategies from a range of resources at a variety of levels.

In this chapter we focus on resilience specifically within adjustment domains relevant to engineering education. In so doing, we draw upon a definition from higher education literature, in which resilience is “*conceptualized as an effective adaptation to stress, adversity or change*”(Brewer et al., 2019, p. 5), primarily in relation to positive outcomes. We therefore consider the sources of stressors, adversity, and change as those experienced as a direct result of studying engineering, including transitioning to university; workloads and deadlines; challenging content and assessment; poor instruction; feedback and failure; problems involving uncertainty

and complexity; competitive environments; difficult interpersonal relationships with educators and peers; and isolation and social pressure. Although macro- and chrono-level applications and implications can be incorporated into pedagogy through deliberate learning activities and discussions, this chapter focuses on micro- and meso-level systems.

Table 2.16.1: A summary of Bronfenbrenner's (1979) bioecological systems model adapted from Jensen et al. (2023) for students in engineering education contexts.

<i>Model level</i>	<i>Description</i>	<i>Examples</i>
Microsystem	People or elements that regularly impact individuals	Cohort peers, friends, family, educators
Mesosystem	A system of microsystems comprising the interrelations among two settings in which a student participates	Multi-setting participation whereby a student participating in curricular and extracurricular activities, forms an interconnection between settings. This creates a first-order social network allowing for inter-setting communication and knowledge
Exosystem	Environments in which students are not directly placed, but which impact them	Higher education and academic policy, education funding and resources
Macrosystem	Broader cultures	Job market, social norms, current policies
Chronosystem	Broad changes occurring over several years	Changes resulting from globalisation, COVID pandemic, technological advancements, shifts in social norms and political views

2 Why teach resilience?

Even before the COVID-19 pandemic intensified the focus on resilience as a contributor to student success (Brammer, 2020), its importance in engineering had been recognised. This focus appears to be driven by a presence of several adversities, including perceived heavy workloads (e.g., Jensen et al., 2023) as well as reported rates at which engineering students suffer mental health issues relative to those studying other disciplines (Danowitz & Beddoes, 2018). These factors may contribute to the high rates of attrition among engineering students (Hunsu et al., 2021). In their systematic literature review, Winkens and Leicht-Scholten (2023) found several reasons why being resilient is essential within engineering education: persistence in

completing studies; adapting to changes to educational settings as a result of COVID-19; learning from failures and errors; coping with stress, adversity, and challenging situations. The development of resilience is thus considered necessary for students to successfully complete a degree, enabling them to pursue an engineering career and succeed in the workplace, as well as withstand shock and burnout.

The importance of resilience is reflected within wider HE literature, where it is considered as a graduate outcome and included within employer surveys. Research has highlighted the need for it to be taught to help ensure that students develop the necessary skills to navigate the workplace (Jackson et al., 2007), where it is referred to as 'graduate resilience' (Hodges, 2017) and 'career resilience', the latter being defined as "*a person's resistance to career disruption in a less than optimal environment*" (London, 1983, p. 621).

Whilst many of the adversities, stressors, or changes experienced in practice bear similarities with those within universities, those associated with the latter are often bounded, developmental, and structured, and include conceptual difficulty, individual competition and regular feedback loops. In comparison, workplace experiences are frequently open-ended and high-stakes and include project failures, design constraints, organisational politics and change, job insecurity, and safety or ethical dilemmas, all of which may carry legal and financial consequences. Accordingly, while educational experiences enable cultivation of capacities that support later professional resilience (Ginsburg, 2014; Martin & Marsh, 2006), these capacities are not entirely generalisable, nor independent of context. In this chapter we draw attention to underpinning psychological and behavioural processes involved in both contexts and focus on pedagogies by which to foster forms of resilience that prepare students for professional contexts.

3 Implementation

Despite the emphasis on resilience, there is limited work detailing associated competencies and skills or teaching approaches (Winkens & Leicht-Scholten, 2023). However, there are many opportunities for educators to incorporate its development in individual modules and entire programmes. Here we highlight characteristics and features of resilience-based learning activities before discussing appropriate pedagogies which can be utilised during delivery. In so doing, we make use of the definition of resilience provided within section 1, which refers to the presence of "*stress, adversity or change*" and "*effective adaptation*" (Brewer et al., 2019, p. 5).

3.1 Characteristics and features of resilience-based interventions

This section outlines interconnected characteristics and features of learning activities designed to support the development of resilience. Some focus on exposing students to challenge, while others emphasise strategies enabling positive adaptation and successful coping. Where relevant, examples are included to illustrate how these features may be applied in practice.

The intention is that these ideas function as a flexible 'menu' from which to select and adapt approaches for your specific teaching context. In doing so, consideration should be given to level of study and scaffolded progression. Supporting development of resilience involves equipping students with appropriate tools and support structures (thus strengthening positive adaptation), before gradually introducing structured and unstructured challenges.

To demonstrate how these features can be integrated coherently, the section concludes with a final example (Example 4). This extended illustration shows how multiple characteristics can be brought together within a single engineering module.

Exposure to stress, adversity, and change

Engineering is commonly viewed as a challenging discipline and there are many stressors present within degree programmes. However, this section encourages you to consider ways in which to present structured challenge.

Engineering modules that include project management content offer opportunities for students to learn stress management under pressure (Čavrak et al., 2019; Vadapalli et al., 2024). While you should start by providing students with fixed deadlines, as they progress you can change project scope and resource availability, necessitating adaptation. Authentic problems and challenges can expose students to incomplete information, uncertainty (Čavrak et al., 2019; Neumeyer & Santos, 2023; Silva et al., 2020), and failure, requiring iteration and continuous improvement (Membrillo-Hernandez et al., 2019), fostering resourcefulness and providing opportunities to positively adapt.

The use of teamwork, which can involve interpersonal conflict and contribution fairness (Čavrak et al., 2019; Steen & Pollock, 2022), offers another way to scaffold development of resilience. For example, team diversity can impact stress levels (Graßl et al., 2023), and students can be pushed out of their comfort zone through the integration of interdisciplinary and inter-year communication and collaboration (Vadapalli et al., 2024).

However, it is important to acknowledge the risk that students become overloaded or struggle with interpersonal conflict and inequitable group work, or are exposed to stereotypical views and deficit narratives that emphasise what they lack rather than the strengths and resources they bring. Therefore, it is important to be mindful of the way they are differentially impacted, and that you have resources to support them to succeed, as will be discussed in the next section.

Effective adaptation

Resilience is a capacity that develops through interaction between individuals and their learning contexts. Although the capacities described here are often framed as individual attributes, they do not emerge in isolation and are cultivated through design of curricula, pedagogies, and environments that legitimise reflection, iteration, and help seeking. The strategies that follow therefore describe individual capacities as structurally enabled within educational programmes.

At the individual level, resilience is strengthened through development of the ability to self-regulate, grounded in self-awareness and meaning making. Structured reflection (as outlined in Example 1) and meditation tasks (Huerta et al., 2021) enable students to recognise stress indicators, monitor emotional responses (e.g., Täks et al., 2014), and regulate emotional states (e.g., Mapaling et al., 2024) before stress escalates into burnout or disengagement. Making explicit links between thoughts, emotions, and behaviour allows students to become better able to tolerate uncertainty, anticipate challenges (Winkens et al., 2024), and identify when further learning is required (Nobutoshi, 2023). This regulatory capacity is reinforced when programmes support physical and mental well-being. Practices include sport, art therapy, breathing exercises, gratitude work, and reframing techniques (Gubaryeva et al., 2024). Self-awareness and reflection also provide the foundation for students to connect developing competencies to meaningful personal and professional goals. Encouraging students to articulate how their abilities align with future aspirations enhances motivation, adaptability, and decision making (Balart et al., 2024). Activities such as purpose mapping help students integrate values, academic learning, and professional identity, strengthening commitment in the face of challenge. Professional skills and employability-focused modules provide a natural context for embedding this integrative work, particularly in engineering education where lifelong learning is central.

Example 1. Reflective resilience and well-being in engineering projects

Level/context. Design, lab, or prototyping modules with iterative technical tasks and regular deadlines.

Time needed. 1-2 Hours for an initial workshop, plus 10-15 minutes per week for guided reflection and well-being activities.

Resources. Reflection prompts, journals, purpose-mapping templates, brief guided meditations, movement breaks, or creative exercises.

Output. Weekly journal entries noting stress indicators, emotional responses, coping strategies, and links between tasks and personal and professional purpose; evidence of using well-being practices to sustain focus and engagement.

Assessment and marking. marks for engagement with reflection and well-being practices, demonstration of emotional regulation, and articulation of purposeful alignment with learning and future engineering practice.

However, resilience is not sustained by individual capacity alone and is shaped by learning environments which normalise help seeking. When educators model supportive communication, students are more likely to access support (Jensen et al., 2023), enhancing their ability to manage adversity (Mapaling, 2024). Interventions can be built into the structure of a module as shown in Example 2.

Example 2. Normalising help seeking in engineering projects

Level/context. *Team-based engineering modules with high uncertainty or open-ended problems.*

Time needed. *30-60 Minutes for an initial orientation, plus structured help seeking checkpoints throughout the project.*

Resources. *Clinics which encourage students to problem solve and resolve errors, consultation hours, question boards, examples linking help seeking to professional success, guidance on asking relevant questions.*

Output. *Documented questions, consultation participation, or evidence of applying feedback to project iterations.*

Assessment and marking. *Marks for timely and effective use of support, demonstration of learning from feedback and making adjustments, proactive engagement in collaborative problem solving.*

Closely related is the normalisation of failure. In engineering practice, iteration and continuous improvement are expected; framing academic setbacks as instructive thus mirrors professional reality (Membrillo-Hernandez et al., 2019). When failure is positioned as part of learning (see Example 3), students are more likely to adopt a growth mindset and persist through difficulty (Campbell et al., 2021). Content focused on time and project management can play a complementary role and be explicitly framed as resilience-enhancing (Antoniadou & Antoniadis, 2024). Teaching should prepare students to anticipate risk, assess the probability of failure, and develop mitigation strategies equips them with tools to navigate uncertainty proactively rather than reactively.

Resilience is also relational, with positive peer interactions and constructive teacher-student relationships contributing significantly to well-being and adaptive capacity (Martínez et al., 2023). Structured teamwork, collaborative problem solving, and supportive social networks provide opportunities for mutual reliance and shared regulation. Students can be guided to recognise how their behaviours influence others' resilience, manage challenging group dynamics, and support peers while maintaining appropriate personal boundaries.

Example 3. Normalising failure in engineering design

Introduce examples of engineering failures or examples that show how failure was avoided. Discuss how concerns were identified, highlighting proactive responses, effective remediation, and learning and adaptation. Seek to balance macro-ethical dilemmas with micro-ethical, 'every-day' mistakes which students may face during their career, and which may constitute 'failure in professional responsibility'. Macro-ethical examples including the Citicorp Center in New York, which required reinforcement following concerns over its ability to withstand strong winds (Witcher, 2020). At a micro-ethical level, examples include withholding uncertainty in calculations or models, selective data presentation, dismissing safety concerns,

failing to learn from safety incidences, prioritising cost above safety, and non-compliance with procedures.

Context. Professional skills or design-based modules

Time needed. 1-2 Hours for introduction with additional time for activities.

Resources. Case studies

Outputs. Presentation outlining failures or near-miss situations and lessons for future projects; identification of transferable competencies and skills and their application; stories that illustrate challenges faced and demonstration of resilience. This could entail encouraging students to share a transformation based on an issue they have faced, such as getting a bad grade and the impact it had on their study habits.

Assessment and marking. Marks for identifying key learnings and making suggestions for improvements.

Example 4. Example of integrating resilience into engineering design education

Set an individual or team-based authentic design task. Ask students to:

- *produce a project plan which anticipates and manages potential risks;*
- *use simulation, modelling, and prototyping to test designs in a safe space;*
- *provide evidence of their iterative process and adaption in response to feedback and/or self-evaluation.*

Additional challenge:

- *set design tasks which require the use of multiple concepts, or for which there are constraints and uncertainty.*
- *make changes to scope and information availability as the project progresses.*
- *increase team diversity.*

Facilitate conversations and reflection and offer consultation hours, making use of a coaching approach to pose questions which help students move through challenge.

3.2 Teaching approaches

This section describes teaching practices which may be adopted to foster resilience.

We first consider design-based learning (DBL), challenge-based learning (CBL) and problem-based learning (PBL), which all share conceptual roots in constructionist theory, and emphasise active, experiential, inquiry-led and self-regulated learning within an authentic (real-world) context, although each approach varies in terms of focus, the type of problems and challenges used to trigger learning, the activities involved, the type of solution students develop, and the role of the educator (Doulougeri et al., 2024). DBL is described first, since design may be enacted within

CBL and PBL. We then describe culturally relevant pedagogies (CRP), story-driven learning (SDL) and role-play, and game-based learning (GBL) and gamification.

DBL

Engineering design is considered central to engineering practice (van de Poel & van Gorp, 2006), with DBL allowing for application of knowledge and skills during design activities, leading to development of a prototype or solution.

Rothbucher and Rothbucher (2018) argue that product failure enhances the perceived value of final designs and has resulted in innovation, making failure an important part of professional routine. These ideas can be translated to the classroom to help normalise failure. For example, Simpson et al. (2017) describe framing failure as key to innovation, claiming that it is critical for engineers to engage in rigorous analysis and evaluation rather than discard failures, allows for knowledge transfer to other engineers and projects. To this end, they define failure as a feature of engineering and argue that learning from failure is an integral part of the engineering curriculum.

CBL and PBL

CBL and PBL have been proposed as approaches to foster the development of resilience (Winkens & Leicht-Scholten, 2023). While both are experiential, student-centred approaches to pedagogy, they differ in that CBL involves open-ended, real-world challenges and different types of knowledge stakeholder, whereas PBL relies more on tackling specific, structured, often disciplinary problems (Doulougeri et al., 2024). As such, the use of PBL and CBL together may be considered as scaffolding progressive development of resilience. PBL can provide opportunities for students to focus on process and act on frequent, formative feedback. This allows them to develop coping strategies, confidence, and adaptability without fear of the output being judged. Students can then be introduced to CBL, which involves gradually increasing complexity.

Service learning or community partnerships are considered as types of CBL which engage students with real-world challenges, requiring them to identify community needs, develop solutions, and reflect on experience to gain deeper understanding and civic engagement. This allows them to connect technical knowledge with meaningful impact, reinforcing self-efficacy, sense of purpose, and long-term motivation (Duffy et al., 2009). However, when adopting these approaches, it is important to focus on reciprocity and avoid exacerbating power imbalances by ensuring mutual benefits and equity for all stakeholders (Delaine et al., 2023).

These approaches are flexible and can be applied throughout the duration of semester-long modules or for shorter time periods. They offer several opportunities to cultivate resilience and one (or more) of the characteristics or features outlined in 3.1 may be incorporated according to student needs. For example, you may vary the levels of complexity, uncertainty, and constraints involved in a problem or challenge depending on the level of study or introduce unexpected scenarios during the project. Team composition can also be varied, for example by introducing members from different disciplines, which brings further challenge to communication.

CRP

Culturally relevant pedagogies (CRP) and related frameworks for culturally responsive and culturally sustaining pedagogies have been explored as approaches to cultivating resilience in engineering education, particularly among students from underrepresented racial and ethnic groups (Garriott et al., 2019; Versfeld et al., 2025). Grounded in asset-based perspectives such as Yosso's Community Cultural Wealth Model (Martin et al., 2016), they emphasise the value of various types of capital that students from marginalised communities contribute to educational spaces. Yosso argues that many educational systems have been influenced by Bourdieu's concept of cultural capital, which often privileges the norms and resources of dominant social groups. In contrast, the Community Cultural Wealth Model recognizes multiple forms of capital that support resilience, achievement, and success, such as *aspirational capital*, "the ability to maintain hopes and dreams for the future, even in the face of real and perceived barriers" (Yosso, 2005, p. 77). By actively affirming cultural identities within learning environments, educators can enhance students' sense of belonging and self-efficacy, which are key foundations of resilience (White et al., 2025).

In practice, CRP is enacted through a variety of strategies which can involve integration of mentorship from culturally similar role models, structured peer cohorts, and community-building activities. These initiatives create 'counter-spaces', allowing students to draw on cultural strengths whilst navigating the challenges of engineering (Martin et al., 2016). Another approach involves modifying curricula by reframing technical content through students' cultural contexts. This includes tackling problems that students observe in their own communities (McAlister et al., 2022) and integrating indigenous knowledge systems as legitimate engineering epistemologies, for example through land-based or indigenous-contextualised design (Mooney et al., 2025). Teaching methods can be adapted to reflect students' cultural values rather than defaulting to the individualistic and competitive structures typical of traditional education. For instance, collectivist assignment structures have been designed specifically to align module concepts with the value systems and communal orientations of Latinx students, with the aim of reducing retention and attainment gaps (Otero-Diaz et al., 2021). Similarly, the design of peer-led study groups has drawn on Ubuntu principles of mutual obligation and support, collective well-being and interconnectedness with the aim of supporting students to navigate adversity and foster resilient communities (Versfeld et al., 2025). These strategies can be implemented in different ways at different scales and integrate easily with pedagogies outlined in this chapter. For instance, culturally relevant principles can inform challenge or project-based learning (see Section 3.2.2) and can be tailored to specific cultural and institutional contexts.

SDL and role-play

Story-driven learning (SDL) can foster resilience by contributing to sense-making through reframing of experiences (Lee & Le Doux, 2025; Morgan et al., 2021), as well as self-awareness, reflection, self-regulation, and mental well-being. Use of narratives

can empower students to reconcile learning experiences with engineering practice and their goals (Freitas, 2024), thus fostering a sense of purpose. Deliberate prompt selection can normalise failure by encouraging students to describe stressful instances and share strategies that helped them control outcomes or feel more confident in their abilities. For example, Whitnall and Hurley (2024) propose an approach whereby students share experiences of failure in a safe space, as well as guided visualisation tasks whereby participants envision achieving a pathway to success. SDL can also foster positive relationships with an audience, facilitating relational resource which can aid in resilience (Lee & LeDoux, 2025; Morgan et al., 2021).

Role-playing can be used to encourage students to consider different perspectives and reflect on opportunities to apply resilience in varying scenarios. For example, Martin et al. (2019) illustrate how role-play can immerse students in challenging conditions, prompting them to adapt and consider the sociotechnical consequences of their decisions.

Game-based learning (GBL) and gamification

Games can be used to enhance students' resilience through increased engagement (Bodnar et al., 2016), motivation (Gamarra et al., 2022), and self-esteem (Prihadi et al., 2018). Hypothetical scenarios introduce opportunities to make decisions under pressure and navigate hurdles. As intended goals are measured against outcomes, students can cultivate self-regulation while varying strategy. Games can also help normalise failure, particularly for individuals who find it difficult to cope with the negative consequences of decisions or challenging scenarios. In such cases, games provide a safe environment in which students can integrate knowledge and develop coping strategies (Türkoğlu, 2024).

Viewed collectively, these suggestions offer multiple entry points through which resilience can be embedded. While they provide conceptual and practical foundations, their success depends on thoughtful, scalable, and context-sensitive implementation aligned with institutional priorities and student needs, as outlined in the next section.

4 Recommendations for implementation and learning

4.1 Reflect upon the role of contextual factors in shaping students' perceptions and experiences of resilience

The conceptual ambiguity (Burke & Scurry, 2024) of resilience means it is essential to critically examine underlying values and assumptions associated with its inclusion in curricula, and to identify aspects that are relevant within specific educational contexts. Without providing clear definitions, there is a risk that it may be interpreted superficially or conflated with related but distinct concepts, such as grit. As Ladson-Billings (1995) argues, what counts as success, what resources students can draw upon, and how they navigate adversity, are mediated by the cultural environments in which learning takes place. There is also a need to consider how resilience presents. For example, in STEM contexts, disciplinary norms around what constitutes a 'good student' may inadvertently exclude students whose strengths manifest differently, for example through curiosity and community engagement rather than prior attainment

(Johnson & Elliott, 2020). Co-creating definitions with students may thus allow for recognition of diverse cultural perspectives.

4.2 Avoid the use of deficit-based language

Educators should make sustained, intentional efforts to avoid deficit-based language and approaches which fail to recognise sociocultural factors and structural inequalities that place the burden of developing resilience on individuals. This is important given findings which demonstrate students' beliefs that development of resilience is an individual responsibility (Wint & Direito, 2026). In practice, this may involve ensuring language focuses on processes over outcomes, and normalising failure. CRP can be used to foreground students' cultural knowledge, community assets, and lived experiences as resources for learning and adaptation rather than positioning culturally diverse students through a lens of deficit (Brown-Jeffy & Cooper, 2011; Ladson-Billings, 1995).

4.3 Balance exposing students to challenging situations with encouraging positive adaptation

A challenge when designing interventions is balancing the focus on exposure to challenging experiences and supporting positive adaptation, prompting broader reflection about supporting students in perceiving stress as a natural part of life and learning, whilst also protecting their mental health. Interventions should thus target both the individual level, for example through development of self-regulation, help seeking behaviour, and mindfulness to cultivate self-awareness and regulation of emotional responses, as well as the micro- and meso-level, for example by facilitating connection and a culture of help seeking. Considering the diversity, equity and inclusion (EDI) issues already present within engineering, including structural gender imbalances and the marginalisation of ethnic minority students, it is important educators understand, and are responsible for, creating environments in which all students can thrive.

4.4 Provide scaffolded support for development

The need for balance between exposure to challenges and fostering supportive environments necessitates scaffolding of challenge level when introducing resilience-based teaching interventions. Students should be equipped with tools such as risk mitigation to help them navigate aspects such as complexity and uncertainty. Likewise, for team projects, providing guidance around expectations, open communication, and conflict resolution, can help students prepare not only for assignments and projects in class, but also for their career trajectory.

4.5 Start small

Educators may be averse to integrating resilience within modules for a variety of reasons including: perceived lack of need; lack of space in the programme; lack of confidence; and limited time and resources. However, integrating resilience does not necessitate extensive overhaul of lesson plans. You can start small by encouraging students to reflect on learning processes and opportunities for improvement. You may

also look for existing opportunities to introduce concepts related to resilience. For example, design modules offer space to discuss the importance of failure and iteration, whereas engineering management modules can be used to introduce strategies used to adapt to changes in project scope, and resource and information availability.

4.6 Explore approaches adopted within other disciplines and cultures

As demonstrated in this chapter, psychology offers frameworks and interventions that can be adapted for engineering contexts. Insights may also be gained from research within fields such as nursing, social work, and medicine, in which discussions regarding development of student resilience are more advanced (e.g., Low et al., 2019).

You should also consider how resilience manifests across cultures and contexts (e.g., see Ungar, 2011) and explore non-Western and indigenous approaches to resilience (e.g., see Ebersöhn, 2019).

4.7 Resources and Further reading

Finally, in addition to the literature referenced in this chapter we also recommend the following two resources to deepen your knowledge, Abulfaraj et al. (2024) on resilience interventions and Khaira and Sayekti(2024) on resilience and well-being in higher education.

5 Conclusion

Resilience is a critical competency that can serve engineers throughout their academic and professional trajectories across the stressors, shocks, and complex challenges they encounter. We encourage educators to adopt approaches to fostering resilience in their teaching. Creating environments that support mental well-being, encourage positive relationships, and normalise help seeking and failure can better prepare students for the multiple challenges they will face throughout their career. Resilience is shaped by the socio-cultural environments in which learning takes place, and its development must be approached with cultural and contextual sensitivity. As Wissing et al. (2022) argue, well-being and resilience are relational and systemic, extending beyond individual traits to consider the ways in which cultural knowledge, values, and social structures shape human flourishing. This resonates with non-Western and African-centred approaches, which emphasise harmony, interdependence, and collective well-being (Wilson Fadji et al., 2022), offering a richer, more situated understanding of how resilience is nurtured.

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2.16

Information Literacy

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The growing complexity of engineering problems means that engineers spend an increasing amount of time working with information from multiple disciplines, making information literacy (IL) a critical skill. Despite this, there is evidence to suggest that engineering students lack confidence and ability to select, evaluate, and use different sources, which is likely to hinder engineering practice and raises ethical concerns in both education (e.g., academic misconduct) and the workplace (e.g., professional responsibility). In this chapter, we first define IL in relation to associated concepts. This is followed by an introduction to key frameworks and standards that outline essential competencies and skills. We then examine the growing importance of IL in the context of technological advances, including the exponential rise in available information and the increasing use of generative artificial intelligence (GenAI). Finally, we explore practical strategies for embedding IL into engineering education, highlighting collaborative approaches that involve specialists such as subject librarians to support effective scaffolding of IL competencies and skills.

1 Definition

Developing information literacy (IL) in engineering students involves agreeing upon a shared understanding of what IL means within the context of engineering education, as well as the competencies and skills involved. Establishing this consensus first requires differentiating information from related concepts including knowledge and data, as well as understanding the hierarchical relationship between them (Ackoff, 1989).

In the context of engineering, data includes *"measurements, surveys and observations"*, which are unusable and *"need to be processed in some way to yield information"* to assist engineers in performing their role (Brodie & Brodie, 2009, p. 138). Knowledge is treated as a special form of information, recalled from memory and *"frequently applied in the day-to-day role of an engineer"* (Brodie & Brodie, 2009, p. 139). New knowledge is thus created when *"we interpret information in light of our prior knowledge"* (Trevelyan, 2014, p. 103). The hierarchical nature of this relationship means that each level can be seen as a precursor to the next and thus data literacy can be viewed as a sub-competence of IL (Schild, 2005).

Although several IL competency standards and frameworks exist across higher education (e.g., ALA, 2000; Bent & Stubbings, 2011), here we draw upon that which the Association of College and Research Libraries (ACRL) provide specifically for science, engineering and technology disciplines. The ACRL defines IL as *"a set of abilities to identify the need for information, procure the information, evaluate the information and subsequently revise the strategy for obtaining the information, to use the information and to use it in an ethical and legal manner, and to engage in lifelong learning"* (ACRL, 2006). It provides five information literacy standards which we will use to inform the definition of IL used in this chapter:

1. Determining the information needed to answer a question or solve a problem.
2. Obtaining the information effectively and efficiently.
3. Critically evaluating the information and its sources and deciding whether to seek additional sources or modify the search process.
4. Using information ethically and legally to complete the given task.
5. Understanding IL as an ongoing process and recognising the need to keep abreast of new developments in the field.

This definition highlights the way that IL intersects with other competencies and skills including lifelong learning, for which it *"forms the basis"* (ALA, 2000, p. 207). Within engineering education research specifically, IL has been identified as one of six major clusters of lifelong learning competencies (Van den Broeck et al., 2024). Furthermore, access to information is increasingly via technology, thus requiring a need to be digitally literate, with Fan and Wang (2022) including information skills as one of five key aspects of digital skills. Bruce (1997) introduces information technology literacy (ITL) as a concept which influences and coexists with IL, and which is defined as *"the knowledge which allows an individual to function efficiently and effectively in whatever circumstance one finds him/herself in a technologically oriented society"*.

IL competencies therefore allow engineering students to engage with a broad spectrum of information in an ethical and efficient manner.

2 Why teach information literacy

Although IL *"is a concern to all sectors of society"* and *"a prerequisite for participating effectively in the information society"* (Information Literacy Meeting of Experts, 2003, p. 1), it is particularly important within the field of engineering for several reasons. Firstly, studies focused on engineering work have highlighted the importance of IL in engineering practice, with Robinson (2010) finding that over 55% of the engineer's workday was spent on the acquisition and provision of knowledge, and Allard et al. (2009) determining that engineers spend one quarter of their time on information-related tasks. Furthermore, the accurate extraction and use of information is considered as fundamental to ethical and responsible practice (Faber et al., 2022), with Messer et al. (2005, p. 4) claiming it allows engineers *"to use the appropriate information, sustainably, ethically and professionally"*. The ACRL (2006) refers to *"unique challenges"* faced by engineering and science disciplines because of their interdisciplinary nature, requiring *"students demonstrate competency ...in unique areas such as experimentation, laboratory research, and mechanical drawing"*. They also claim that it is *"highly important for students in science and engineering/technology disciplines"* which are *"rapidly changing"*, with the curriculum of technical degrees being estimated to have a half-life of less than five years (National Academy of Engineering, 2004). IL is thus a key competency for lifelong learning (Tuyaerts et al., 2025; Van Den Broeck et al., 2024; Wertz et al., 2013), and enables engineers to *"to keep up with new developments and new sources of experimental/research data"* (ACRL, 2006) and adapt to the changing needs of society and technological innovations (Faber et al., 2022).

This need for engineers and students to adapt has become increasingly important in recent decades as digitalisation and widespread use of generative artificial intelligence (GenAI) have led to the spread of deliberately misinterpreted or misleadingly prepared information (Schüller, 2020). Large language models (LLMs) are associated with several limitations in that they can provide incomplete, inconsistent, incoherent, illogical, and indulgent information, meaning that *"AI may promote confirmation bias or path dependency by only telling you what it thinks you want to hear"* (Carroll & Borycz, 2024, p.6) and tend to hallucinate scholarly citations and false information (Chaudhuri & Terrones, 2025).

These trends have resulted in an increased focus on the development of IL competencies and skills, particularly those related to critical evaluation. This growing emphasis on IL is evident by its inclusion within various nationally and globally recognised engineering accreditation criteria (e.g., ABET, 2025; ENAEE, 2021), with Riley et al. (2009, p. 2) claiming that *"students cannot achieve many of the ABET outcomes without developing information literacy skills"*.

Despite recognition of the growing importance of IL, evidence from the engineering education literature suggests that students are not adequately equipped with IL

competencies and skills. For example, both Douglas et al. (2014) and Ross et al. (2011) found first-year engineering students to be overconfident in their ability in IL, with other work finding that first-year students struggle with applying and documenting information during design work (Wertz et al., 2013). Other studies have found that students have trouble differentiating between different types of sources, spend little time gathering information, make little use of references, have issues with citation styles and have a lack of ability to assess the quality of information, evaluate web resources, and use technical papers (Ekwaro-Osire et al., 2008; Tsai & Janssen, 2018). There is also reason to believe that IL education may not sufficiently prepare students with the competencies and skills needed for work as engineers, suggesting the need for authentic interventions, by which we mean those which include the use of sources typically used by engineers within their work (e.g., patents, standards, test data), to address realistic engineering problems. For example, engineers have been found to rely on knowledge of contacts and have less access to knowledge behind a paywall (e.g., Manuel et al., 2005; Paretto & Asaro, 2008), with Phillips et al. (2019) finding that although engineering students and professionals regularly make use of search engines such as Google, practicing engineers lack sufficient access to resources; instead, they tend to consult with peers and make use of propriety information.

3 Forms of implementation

3.1 *Integration of IL within individual modules and entire programmes*

You can incorporate IL into teaching in a variety of ways at module and programme level, the latter allowing for scaffolding and progressive development of IL based competencies and skills. For example, undergraduate instruction may focus on identification and selection of credible sources and citation practices. At graduate level, students are more concerned with developing as independent researchers and therefore need to be able to evaluate information and identify limitations and gaps in literature to inform future research topics (Smyser & Bolognese, 2023).

At a module level, you can incorporate IL into general engineering classes (e.g., searching for books in the library and practicing citation) or by demonstrating engineering- focused databases and technical standards (Phillips et al., 2018). For example, in the case of the former, IL could be considered as integral to first-year engineering modules, in which students are taught foundational skills necessary to be successful in disciplinary study and the engineering profession (Faber et al., 2022). In comparison, interventions with a technical or subject focus can be included within design modules at different levels (e.g., introductory to capstone) (Phillips et al., 2018). To this end, Fosmire (2012, p. 47) claims that “*engineering design problems provide a real-world context for the underlying skills and techniques that students learn during their coursework*”, and Atman et al. (1999) describe a relationship between design quality and breadth and depth of information obtained.

While individual modules play a vital role in reinforcing IL skills, the lack of scaffolding and inconsistency in approaches used (Ford-Baxter et al., 2022; McAdams &

Glauber, 2017) suggests the need for programme-wide integration, which helps ensure consistency and progressive development. Williamson et al. (2019) describe a strategic, top-down approach to the incorporation of IL within engineering, involving building relationships with academic stakeholders and the use of hands-on modules and specific instruction throughout a degree. One way in which you could integrate IL at a programme level is by using a curriculum mapping process. For example, within engineering, McAdams and Glauber (2017) describe making use of the ACRL framework in conjunction with a curriculum map of ten undergraduate programmes to plan and design scaffolded and sequenced opportunities for students to engage in IL at strategic points in their degree.

3.2 Teaching methods

A range of approaches can be used when teaching IL skills, with the ACRL (2011) advising that *"multiple modes should be incorporated whenever possible"*. Your selection will depend on several factors including cohort size, availability of technology, and session learning outcomes. For example, traditional lecture style sessions may be used when delivering basic core concepts, with active learning approaches (e.g., problem-based learning) being utilised when guided assistance is beneficial, e.g., when providing students with opportunities to practice use of databases and other tools. The use of active approaches such as problem-based (PBL) and project-based learning (PjBL), which engage students with open-ended, authentic scenarios, has been shown to help engineering students to connect IL theory and practice. This resulted in increased levels of interest and engagement when compared to traditional lecture-based learning (Hsieh & Knight, 2008), as well as improvements in technical knowledge in addition to IL-based skills and competencies. Although the ACRL (2011) recommends that *"instruction should employ active learning strategies and techniques"*, the adoption of such pedagogies may be limited by cohort size (Cioc et al., 2022).

Equally, assuming the availability of appropriate technological resources, you may choose to adopt a blended or hybrid approach involving the use of computer-assisted instruction (e.g., web tutorials or web-based instruction) and self-directed independent learning.

3.3 Practical examples

In this section we include examples of activities which could be integrated into engineering modules. In so doing, we make use of the ACRL (2016) IL competency standards for higher education and therefore group activities into those focused on: recognising the need for information; locating information; evaluating information; ethical and legal use of information; and lifelong learning. To some extent, the groupings are sequential, and it is likely that you begin by familiarising new undergraduates with different types of sources and information and how to access them, before focusing on evaluation and synthesis. For each grouping we reflect on ways that the design of interventions can allow you to support the progressive development of students' IL competencies and skills.

Examples are provided for select competency standards, followed by a longer exemplar which incorporates some of these examples into one complete task covering all five competency standards (Example 5).

Identify the information needed for a problem or question

- Break authentic, open-ended problems into sub-problems (if necessary, this can be done using AI).
- Identify knowledge gaps and develop precise research questions.
- List potential sources of different types of information needed to contribute towards a given problem.
- Develop a search strategy (with justification for decisions made) by identifying appropriate investigative methods; different sources and formats of relevant information; and key terms and synonyms. Compare strategies with peers to determine how differences in approach result in different outcomes.

Progression: as students develop, they will become more confident and efficient in identifying the necessary information and you could therefore increase the complexity of problems, necessitating input from a wider variety of disciplines and/or types of sources, which, at times, may bring conflicting insight.

Locating information

- Use engineering databases to find a set number of high-quality sources relevant to a given question within a set time.
- Compare results from searches using keywords and those using controlled vocabulary, classification schemes, or subject headings.
- Obtain further sources of information by using the reference list and citation tracking of one provided article.
- Compare the efficiency and reliability of results from a general web search and a technical or scholarly source.
- Obtain and extract information from standards and specifications to complete a specific design task.
- Iteratively improve AI prompts to promote precise information seeking.

Progression: as students develop, you should notice them becoming more confident in searching for data and information and make use of more sophisticated techniques to optimise searches. You can thus provide them with problems or questions which require them to locate information from a wider range of (unprescribed) sources from the university library and external digital resources.

Evaluating information

- Identify the information relevant to a given problem (from an extended text or a limited number of prescribed, high-quality resources) through a range of reading and search techniques.
- Produce an annotated bibliography which summarises and evaluates the differences between sources and explains their relevance to a specific (design) problem.

- Revise a query based on critical evaluation of initial sources.

Example 1. Use of frameworks to evaluate sources

Apply frameworks such as the CRAAP test, this referring to Currency (how recent is the information), Relevance (does the information directly answer the research question?), Authority (who is the author or publisher?), Accuracy (where does the information come from and how is it supported?), Purpose (why was the information created?).

Level/context. You could integrate this within introductory modules which focus on development of professional skills, or in discipline-specific modules in which information is required, for example to inform design.

Time needed. The duration of the activity can be varied (e.g., from 1 to 2 hours) depending on the number and length of sources provided and whether students work in teams or individually.

Resources. Curated pack of sources (it is beneficial to include a range of sources which are likely to result in different evaluations) relevant to module content; activity sheets (see Faber et al. (2022) for activity sheets which support students in assessing information by utilising the CRAAP test).

Output. A short list of suitable sources to address a problem or question, or a ranking of sources on the same topic according to their relevance.

Assessment and marking. Award marks for correct application of frameworks.

Example 2. Evaluating contradictory sources of information

Provide students with different (contrasting) sources about the same technology (e.g., a government report, a trade body report, a corporate white paper, an environmental NGO blog, and a peer-reviewed article about carbon capture). Ask them to evaluate and synthesise sources in relation to a given problem or question.

Level/context. You could include this in more advanced modules which consider the need for responsible and ethical engineering or modules, where students need to consider a wide range of information to inform decisions, e.g., a design module.

Time needed. The duration can be varied (e.g., 1-2 hours) depending on the complexity and length of the sources and whether students work in teams or as individuals.

Resources. Contrasting sources; guidance identifying and evaluating arguments.

Output. An argument map illustrating the logical structure of arguments made in the sources, presenting assumptions and evaluating the support an argument offers for a conclusion. Alternatively, use role-play exercises and debates whereby students adopt opposing viewpoints.

Assessment and marking. *Award marks for correct identification of arguments, sources of bias, assumptions, and inferences, and for the justification as to the degree to which the arguments offer support for the conclusion.*

Example 3. Critical use of GenAI

Ask students to evaluate a GenAI output which focuses on a specific research topic. They should fact-check and validate claims using real sources, analyse how well the output captures key points, and identify gaps and errors.

Level/context. *You could include this example at a variety of levels where research is required (e.g., design modules, final-year research projects).*

Time needed. *The duration of the activity can be varied (e.g., from 1-2 hours).*

Resources. *Sources to aid in validation and evaluation of outputs, research questions for students to answer by iteratively improving GenAI prompts to promote precise information seeking.*

Output. *An annotated copy of the GenAI output which indicates errors; a paragraph summarising how well the output captures the key points.*

Assessment and marking. *Award marks for sourcing evidence to support the correct identification of errors and omissions in the output.*

To support student development and progression in the area of evaluating information, you may initially provide students with curated source packs to evaluate. As they develop, they should become increasingly independent in their ability to obtain, evaluate, and use sources. You could provide them with problems or questions which require them to locate and evaluate (complex and contradictory) information from a wider range of sources.

Ethical and legal use of information

- Read short excerpts from engineering reports with different citation practices (some plagiarised, some paraphrased, and some correctly cited). Identify examples of ethical attribution (giving proper credit to original authors through accurate citation and referencing) and correct examples of improper attribution.
- Determine whether it is more appropriate to paraphrase or quote extracts provided.
- Provide a reference for a given source using a variety of referencing styles.
- Consider the ethical use of information by analysing a case involving intellectual property in engineering, such as patent infringement or copyright violation (e.g., software code copied without permission, or copyrighted 3D-printing designs reproduced unlawfully). Discuss how ethical engineering practice requires respecting intellectual property rights by obtaining permission where necessary, complying with licensing agreements, and giving appropriate credit to creators.

- Identify, discuss, and debate ethical issues around the use of information (e.g., open access to information in the context of a specific engineering problem, and the use of AI-generated content in engineering decision making).

To support student development and progression in the area of ethical and legal use of information, realise that as students develop, you should find that they become more confident in paraphrasing and make use of quotations in a limited, purposeful manner. Their arguments around ethical use of information will become stronger and more nuanced as they become more confident in obtaining, evaluating, and synthesising information from a wider range of perspectives.

Example 4. Engineering failures

Present an engineering failure and ask students to identify which information gaps, ignored data, or misinterpreted sources contributed to the failure.

Level/context. You could include this example within introductory modules which consider the need for responsible and ethical engineering and acts to demonstrate the importance of IL to students.

Time needed. The duration of the activity can be varied (e.g., from 15 mins to up to an hour) depending on the complexity and length of the case study and whether students work in teams or as individuals.

Resources. Case studies of engineering failures.

Output. A list of information gaps or examples of misinterpretation.

Assessment and marking. Award marks for identification of sources contributing to failure along with an explanation of the role each played.

Extension task. Students could propose methods to ensure the absence of information gaps or misinterpretation of sources in future.

Lifelong learning

IL and lifelong learning are complementary, as a commitment to lifelong learning supports the development of IL competencies, while IL itself is a key lifelong learning skill that enables engineers to keep pace with new developments in a rapidly evolving field. Development of the aforementioned IL competencies (see the associated five standards listed in Section 1) can be supported by the use of self-evaluation tasks (see Phillips and Zwicky (2018) and Ross et al. (2011) for an example task) and reflective journals (see Davidson Squibb & Mikkelsen (2016), who provide example tasks and reflection as well as accompanying marking rubrics). Such tasks serve as tools for prompting metacognitive thinking, encouraging students to reflect on challenges faced during research, how they adapted, lessons learned, and how information needs evolved during the project. Prompts can encourage the documentation of evolving strategies, databases utilised, search terms and query refinement, and replacement of sources based on evaluation or the limitations of information retrieval systems.

Activities which promote IL as the basis of lifelong learning are provided below.

- Explore a cutting-edge technology (e.g., hydrogen fuel cells, AI-driven structural monitoring, quantum materials) and summarise the current state of research and future directions by making use of a number of sources.
- Search relevant job postings and identify skills and knowledge areas in demand; then find scholarly or industry sources or identify professional organisations and conferences to learn more about them.
- Determine IL (and general development) needs, for example competency in use of new technologies and approaches to accessing and managing information, as well as emerging and advancements in the field.
- Produce a journal which includes reflections on learning, feedback, gaps in knowledge and future aims.

Supporting student development and progression in the area of lifelong learning : as students develop, they may become more autonomous in their reflection and learning, and you can provide them with fewer prompts and guidance.

Example 5. A scaffolded approach to embedding IL competency standards within a research/design module.

Task

Provide an authentic, open-ended (design) problem or research question which requires students to address environmental, economic, and social perspectives within a defined context. In some cases, you may choose to select specific design tasks which require students to obtain and extract information from exact standards and specifications.

Outputs

Output 1:

- *Ask students to break down the problem or research question into sub-problems (with help using GenAI), identifying a variety of types and formats of potential sources for information, with a realistic search strategy and timeline to acquire the information.*
- *Award marks for inclusion of appropriate investigative methods; a list of possible sources of relevant information which takes account of the value of different resources and formats relevant within the field; key terms and synonyms; and justification for decisions made.*

Output 2:

- *Ask students to produce an annotated bibliography, summarising differences between key sources and explaining their relevance to the problem or question.*
- *Award marks for the ability to question sources of information and the reasonableness of conclusions, for example by evaluating differences in reliability, validity, accuracy, authority, timeliness, quality, currency, and relevance of sources.*

Output 3:

- *Ask students to produce a portfolio demonstrating their growing research skills and metacognitive awareness of information-seeking processes. This could include (1) a search strategy reflection log which includes databases, search terms, and filters used, revisions to their strategy based on evaluation of search results, and the limitations of the information retrieval systems; and (2) reflective pieces focusing on their information gathering process, the relevance of the search results, and the limitations of the information.*
- *Award marks for the ability to describe and reflect upon the approaches taken, justification for the need to change the approach, and the inclusion of clear adaptations.*
- *Extension task: you may also wish to ask students to reflect on how the skills developed prepare them for ongoing learning in engineering.*

Output 4:

- *Ask students to produce a design or research report.*
- *Award marks for synthesis of relevant information, critical engagement with the literature, ability to justify decisions and draw conclusions based on information, and thorough and accurate citation (in text and in bibliography).*

Additional considerations

Teamwork and peer feedback can be utilised for large cohorts.

Librarians could provide sessions focused on locating relevant resources and search strategies (e.g., use of controlled vocabulary, classification schemes, or subject headings), as well as methods by which to manage and organise sources of information (e.g., citation management software).

4 Recommendations for implementation and learning

In this section we conclude with practical insights and guidance and discuss some of the challenges involved in implementation, as well as considerations to be made with respect to transferability.

4.1 General recommendations

Scaffold the development of IL skills across the programme levels

Reinforce IL at multiple points across the programme to ensure systematic exposure and ongoing practice. Introducing basic IL skills and gradually increasing their complexity provides scaffolding and enables cumulative learning, allowing students to develop mastery over time.

Such an approach is less likely to lead to the superficial understanding, minimal long-term retention, or lack of transferability that are often associated with single one-shot library sessions which suffer from a lack of time to cover discipline-specific resources, recap on difficult topics, and engage with students (Williamson et al., 2019).

Furthermore, scaffolding helps ensure that the number and variety of (digital) tools and information sources do not overwhelm students and increase the cognitive burden, especially when introduced in tandem with technical content.

Ensure that IL content is embedded within the discipline and relevant to engineering practice

Ensure that IL is embedded into core engineering modules (such as those discussed in 3.1), that it is contextually relevant, that it is not treated as an isolated skill, and that students do not confuse technical adeptness with IL (Wilkes et al., 2015). Retention and application of IL concepts have been shown to be more efficient when taught within students' discipline (Ragains, 2013), and you should therefore focus on providing point-of-need instruction and structured assignments which require students to research specific, manageable, and useful topics (Feldmann & Feldmann, 2000), and to reflect on the way that IL-based competencies are applied in practice. This involves spending more time focusing on accessing and evaluating a variety of information types (Phillips et al., 2019) and the inclusion of real-world tasks that involve using technical standards, patents (Phillips & Zwicky, 2018), and discussion of ethical use of intellectual property.

Focusing primarily on textbooks and limiting access to discipline-specific resources (e.g., technical standards) may hamper skill acquisition and undermine students' readiness for engineering practice (Phillips et al., 2024; Tuybaerts et al., 2025), with findings from a three-round Delphi with 15 engineering industrialists showing that participants believed that higher education focuses too much on the theoretical aspects of IL and that it is best developed through practice, for example through the use of PBL.

Collaborate with librarians

As information professionals, academic librarians are well-positioned to support your teaching, and there is evidence to suggest that engineering students are generally complimentary of librarians' knowledge and teaching ability (Bakermans & Ziino Plotke, 2018; Omarsaib, 2023).

Librarians can contribute to the delivery of one-shot sessions, or partner with you to identify knowledge gaps, develop approaches, and co-deliver content. While you may understand cohort characteristics and bring expertise in curriculum design, assessment, and disciplinary content, librarians contribute expertise in identifying the research topics, information resources, databases, and search strategies that best support module learning outcomes, as well as in organising, evaluating, and locating relevant resources (Wilkes et al., 2015). Together, you provide complementary skills which can be utilised through the development of trusting, open relationships in which you understand and respect what each party brings to the team.

Ensure IL competencies are assessed and rewarded

IL competencies should be incorporated into marking criteria for summative assessment of project deliverables, thus making the value of IL explicit to your

students (Smith Macklin, 2001). Without regular assessment, you may lack the ability to identify students' skill gaps or evaluate the effectiveness of instruction. Assessing the varying IL ability of first-year students can be used to inform the development of subsequent curriculum (Bakermans & Ziino Plotke, 2018). If you have scaffolded the development of IL-based competencies and skills over time, you should also ensure that the assessment is designed to assess that progression. When designing an assessment, it is important to take into account the context in which competencies will be applied; you should therefore focus on developing marking criteria which align with the application of identified IL competencies in authentic tasks (for an example see Smyser and Bolognese (2023), who provide an assessment brief and adapted rubric for team-based student research and capstone projects).

4.2 Adaptability and challenges

Implementing IL instruction in engineering education requires thoughtful adaptation to varying institutional and contextual factors and challenges.

Institutional culture and support

Institutional culture around the value of IL impacts upon its integration within engineering curricula, with engineering librarians reporting difficulties in gaining buy-in from academic staff to integrate IL learning into their coursework (Wilkes et al., 2015). Institutionalising IL requires targeted development opportunities and appropriate resource allocation, allowing for sustainable and systematic development of IL skills (ACRL, 2016). In the absence of institutional support, initiatives tend to rely heavily on individual academic champions (Manuel et al., 2005) and pilot projects, making them vulnerable to staff turnover and shifting priorities. In the case of the one-shot approaches typically used in these instances, it is advised *"to best use the limited time available for instruction"* by focusing *"less on tools, such as specific databases, and more on transferable skills"* (Waters et al., 2012, p. 131).

Technological resources and infrastructure

Technology can be used to enhance IL education in a variety of different ways. Firstly, when teaching large student cohorts, it is advantageous to adopt blended learning approaches which include online content, digital modules, and automated assessment. This approach offers several benefits, allowing students to learn at their own pace whilst also reducing the workload of librarians (Zhang et al., 2015). It has been shown to improve information seeking self-efficacy, as well as performance (Tang et al., 2022). Secondly, digital tools such as citation managers and collaborative platforms can be used to streamline research processes and promote better organisation. Finally, a wealth of opportunities emerges as the use of GenAI continues to become more widespread. For example, LLMs can assist in generating relevant keywords and develop search strings, as well as formatting references. It can also support the development of a concept map and research questions when planning research projects or learning about complex topics (Carroll & Borycz, 2024; Chaudhuri & Terrones, 2025). Students may also hone their ability to critically evaluate information

by making use of outputs of GenAI (Lo, 2023) before comparing them with peer-reviewed publications on the same topic.

However, a critical approach should guide the integration of technology into IL-based teaching. The advent of GenAI means there is also an increasing need for us to focus on introducing the technical, operational, pedagogical, and ethical aspects of AI, and ensure that students are aware of how the technologies work to support IL, as well as the implications for academic integrity. Your instruction should focus on providing students with fact-checking techniques and critical thinking strategies that can be employed when making use of AI outputs. At the same time, it is important to help students determine instances when it is appropriate to use this technology (taking account of local academic standards). There is also a need to consider issues such as digital poverty; face-to-face workshops and printed guides remain essential to ensure equitable access to IL, particularly in contexts where technology is limited. Institutions with limited access to discipline-specific databases or technical standards may place greater emphasis on open access resources (Phillips et al., 2024).

Student resistance

Very little work investigates students' perception of IL instruction. As discussed in Section 2, the existing literature tends to focus on students' overly optimistic perceptions of their own ability, which has been framed as a challenge to equipping students with IL (Douglas et al., 2014). As educators, we therefore face the challenge of demonstrating the need for its inclusion within modules and programmes, which can be facilitated by the use of authentic tasks which bear relevance to engineering practice. Despite students tending to underestimate the need for instruction in IL, we should not overestimate their baseline IL competency. This is particularly important in the case of diverse student cohorts, who may have varying experience in IL training.

4.3 Resources and further reading

Finally, in addition to the literature cited in this chapter, we also want to recommend the following resources to deepen your knowledge: *Information literacy for science and engineering students* by DeJong (2024) and *The information literacy framework* by Julien et al. (2020).

5 Concluding thoughts

In this chapter we have highlighted the growing need for IL skills, driven by the increase in information availability, the variety of information types utilised by engineers, the reported lack of competency by students, and a misalignment between teaching and workplace practice. We subsequently provided a summary of the key IL competencies and skills relevant to engineering students and guidance to support their intentional and scaffolded integration within engineering education programmes.

Importantly, IL should be understood as a continually developing competency rather than a fixed body of knowledge. While this chapter offers guidance for developing students' ability to locate, evaluate, and apply information, the rapid expansion of scholarly and technical resources, together with the growing influence of GenAI,

requires ongoing review and adaptation of instructional approaches. As engineering educators, we should thus cultivate a reflective and critical approach to information practices, ensuring their methods remain effective and relevant in a rapidly changing professional and technological environment.

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2.17

Autonomous Motivation, Learning Beliefs and Learner Identity

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Keywords: *autonomous motivation, learning beliefs, learner identity, active learning, problem-based learning*

This chapter synthesises three interconnected competencies: autonomous motivation, learning beliefs, and learner identity that are often examined separately in engineering education. We review key learning theories related to these competencies, identify the factors that influence their development, and summarise empirical evidence on how they are assessed and why they are significant for engineering education. We then introduce four active learning approaches to support competency development: problem-based learning (PBL), project-based learning (PjBL), case-based learning (CBL), and design-based learning (DBL), illustrated with two examples from Aalborg University, Denmark, and Swansea University, UK. Drawing on both theory and practice, we advocate for a holistic approach to understanding these competencies, fostering inclusive learning communities for students, encouraging student ownership, engaging with real-world problems, promoting deep reflection, and emphasising social awareness and responsibility.

1 Definition

This chapter discusses how three key competencies: autonomous motivation, learning beliefs, and learner identity can be embedded in engineering education through targeted, evidence-based approaches. Modern engineering requires graduates who are not just technically skilled but possess the abovementioned competencies to persist in the engineering field, adapt to rapid change, prepare for future professions, and engage in lifelong learning. However, the interconnected nature of student learning and persistence has not always been fully addressed in engineering education. This chapter thus adopts a synthesized, holistic approach to understanding autonomous motivation, learning beliefs, and learner identity.

We begin by reviewing relevant theories, defining and synthesizing the three competencies in an interconnected manner. We then identify key factors influencing their development and summarise empirical evidence on their assessment and significance in engineering education. Finally, we illustrate their application through four active learning approaches, two cases from Aalborg University, Denmark, and Swansea University, UK, and recommendations for implementation and learning for educators and practitioners.

1.1 Concepts

To begin this synthesis, we adopt the definitions most commonly used in educational research, as follows.

- *Autonomous motivation.* Intrinsic motivation, doing something because it is inherently interesting or enjoyable or motivating oneself by focusing on positive external factors (Ryan & Deci, 2000).
- *Learning beliefs.* A person's subjective judgements about the relation between learning and his or her values or attributes (Fishbein & Ajzen, 1975).
- *Learner identity.* "The way in which individuals see themselves as learners, seek and engage in life experiences with a learning attitude, and believe in their ability to learn" (Kolb & Kolb, 2009, p. 5).

The three concepts are viewed as deeply intertwined; they dynamically evolve through reciprocal interactions over time (Sade, 2009). Learning beliefs are closely linked with autonomous motivation: students with positive beliefs are more motivated, adopt diverse strategies, and engage more willingly (Kramer et al., 2024). When learning is meaningful and self-determined, students demonstrate greater persistence, creativity, and responsibility (Ryan & Deci, 2000). Through sustained engagement in learning activities, learners develop their societal and professional identity that organises their beliefs, motivation, and approaches to sustainability and collaboration (Sade, 2009).

1.2 Literature review of relevant theories

The synthesis of the three concepts shapes how learners engage with, persist through, and derive meaning from their educational experiences. Several existing theories help

explain the connections among them, which can be grouped into three perspectives: motivation-centred theories, identity development theories, and integrative theories.

Motivation-centred theories, including Self-Determination Theory (SDT) (Ryan & Deci, 2000), Expectancy-value Theory (EVT) (Wigfield & Eccles, 2000), and Achievement Goal Theory (AGT) (Anderman & Anderman, 1999), explain how learners' beliefs and values shape motivation, engagement and goal orientations. SDT explains how autonomy, competency (including beliefs about one's ability), and relatedness support autonomous motivation. EVT illustrates how beliefs and values mediate between identity and motivation, translating identity-based self-understanding into motivational energy. AGT explains how beliefs about mastery and performance shape goal orientation and motivation.

Identity development theories, such as Erikson's psychosocial development and Marcia's identity status paradigm (Côté & Levine, 1988), alongside moral development theories (Kohlberg & Hersh, 1977), emphasize how identity formation processes, including exploration, commitment, and ethical reasoning shape learners' beliefs, values and motivation. These perspectives position identity as an overarching construct through which learners interpret experiences, form beliefs, and develop motivation.

Integrative theories, including Social Cognitive Theory (Bandura, 2001) and Transformative Learning Theory (Daramola, 2018), highlight the dynamic and reciprocal relationships among beliefs, behaviours, identity, and motivation within social and experiential learning contexts. They emphasise how interaction, reflection, and disorienting dilemmas reshape learners' perspectives across cognitive, emotional, and social dimensions.

Taken together, these three perspectives clarify the interconnectedness of the three concepts: motivation-centred theories emphasize how beliefs shape motivation, indirectly contributing to identity development over time (longitudinally). Identity development theories highlight how identity influences both motivation and beliefs (hierarchically), while integrative theories address the dynamic relationships among all three (reciprocally).

1.3 Etymology

The conceptual integration of motivation, belief, and identity has evolved over time from compartmentalised views of learning toward a more holistic, systematic understanding. Early behaviourist perspectives emphasised external reinforcement while largely neglecting internal beliefs, treating motivation, beliefs, and identity as separate domains (Skinner, 1957).

With the cognitive shift in the 1970s and 1980s, beliefs were recognised as important mediators of learning, while motivation was explained through expectancy-value and attribution theories (Wigfield & Eccles, 2000). This shift highlighted their fundamental interdependence, showing that learning requires alignment between what learners find motivating, what they believe about learning and themselves, and how they see themselves as learners (Wigfield & Eccles, 2000). These frameworks have changed

from addressing linear, fixed, and homogeneous problems to adopting a complex and dynamic approach, where learners' psychology is seen as adaptive, and positive development emerges when the three concepts are aligned and mutually supportive.

Later, constructivist and socio-cultural perspectives highlighted how epistemological beliefs shape learning (Hofer & Pintrich, 1997), and how self-determination theory emphasises autonomy, competency, and relatedness as key to autonomous motivation (Ryan & Deci, 2000). These frameworks bridge individual psychological processes with social and cultural contexts, aligning with 21st-century competency models that emphasise learner agency, adaptability, and lifelong learning. They have taken a more holistic and domain-specific approach, showing that beliefs, motivation, and identity are reciprocally interrelated and shaped by disciplinary practices and societal expectations.

1.4 Systematic approach

While previous research has largely framed these concepts as psychological constructs, they can also be understood as developable competencies that engineering educators and practitioners can support students through pedagogy and instructional strategies. Identifying factors that influence the development of autonomous motivation, learning beliefs, and learner identity is therefore a necessary step.

In classroom settings, engineering students' motivation is strongly influenced by their perceived difficulty of and interest in the subject, learning goals, sense of ownership over learning, and perceived connection to real-world scenarios. It is also affected by teachers' interactions with students, teaching style, subject expertise, and the quality of feedback (Wijnia et al., 2024).

The development of students' learning beliefs is shaped by students' prior experiences, their confidence in organising and executing learning tasks, their estimations that their actions will lead to desired outcomes, and their perceptions of their ability to achieve success through effort. Contextual instructional factors, including teaching methods, type of assessment, and teachers' support and recognition of students' efforts, also play a key role (Kramer et al., 2024; Wijnia et al., 2024).

Learner identity development is a dynamic and complex process shaped by both internal factors such as personal goals, beliefs, motivation, interests, prior knowledge and experience, and external factors such as teacher-student interactions, classroom environments, institutional norms (Jiang et al., 2024; Pierrakos, 2025; Pierrakos et al., 2009). As engineering students make sense of new learning experiences, they form a sense of themselves as learners, which in turn shapes their beliefs and motivation.

These factors call on educators and practitioners to adopt a holistic perspective that considers intrapersonal, relational, and contextual aspects of students' competency development. They are also encouraged to engage students as 'whole persons' by supporting subject knowledge (head), practical skills and actions (hands), and affective and emotional engagement (heart), rather than focusing solely on content delivery (Best, 2008; Pierrakos et al., 2024)

1.5 Contextual variations and cultural considerations

The three concepts manifest differently across cultural and educational contexts. In individualistic cultures, autonomous motivation may emphasise personal interest and choice, learner identity focuses on individual achievement and self-actualisation and learning beliefs emphasise personal control and individual capability (Kramer et al., 2024; Ryan & Deci, 2000). In collectivistic cultures, autonomous motivation may be more closely connected to community contribution and social responsibility, learning beliefs emphasise effort, persistence, and collective learning processes, and learner identity centres on membership in learning communities and the fulfilment of social roles (Kramer et al., 2024; Wigfield & Eccles, 2000). In higher education, student learning often focuses on the development of a broad learner identity, sophisticated beliefs, and autonomous motivation for personal knowledge. In contrast, professional learning contexts in engineering link identity to career development and social contributions, beliefs to continuous learning and adaptation, and motivation to stay up to date in rapidly changing fields (Godwin et al., 2016).

2 Why teach autonomous motivation, learning beliefs, and learner identity competencies

This section begins with an examination of how the three concepts have been explored and developed in prior studies, and their significance for learners, educators and practitioners. Although existing theories have highlighted the convergence of the three concepts within a holistic perspective, the present analysis focuses specifically on autonomous motivation and beliefs. Learner identity is acknowledged as an overarching concept that provides interpretive coherence to these dimensions, but it is not addressed in detail here. This delimitation allows us to establish a clear foundation for understanding the roles of motivation and beliefs, before considering their integration with identity in suggestions and recommendations.

2.1 Empirical evidence

This section describes previous empirical research on the timing of examining beliefs, motivation, and identity development, and findings of how these competencies change over time. Prior literature suggests that educators and practitioners measure these competencies at multiple stages, such as mid- and end-of-semester within a single term, across consecutive semesters, before and after instructional interventions, and through longitudinal comparisons of different cohorts of students over the years (Brown et al., 2015; Kramer et al., 2024; Morelock, 2017).

Previous studies also indicate that beliefs, motivation and identity may increase, decrease, or remain stable over time. For example, by following the same student cohorts over four years, Cech (2010, 2014) reported a decline in engineering students' beliefs in professional and ethical responsibilities, social awareness, and understanding the consequences of technology use during their studies. This shift was attributed to the limited emphasis on ethical engagement within their engineering programmes. Another study examining changes in student motivation within a semester-long engineering module found that students' motivation declined when they were exposed

to monotonous teaching styles, theory-heavy teaching, lecture-based formats, and limited interactions with teachers (Hauzel et al., 2024). Students' motivations evolve and curricular experiences shape students' beliefs as learners and as engineering students (Pierrakos et al., 2016; 2024).

In contrast, experiential interventions such as a ten-day field trip enhanced students' beliefs about the role of science and technology in society by immersing them in authentic contexts. It offered students hands-on fieldwork experience, during which they lived closely with the situated environment, which strengthened their belief system (Nesbit & Mayer, 2010). Similarly, industrial engineering students demonstrated higher autonomous motivation when engaged in semester-long projects involving real cases (Pernia-Espinoza et al., 2025). Learner identity can also be developed through meaningful engineering-related experiences, particularly in the first year of study (Pierrakos et al., 2009; 2024).

In summary, students lose motivation, experience declining beliefs, and become disengaged when they lack a sense of ownership over learning, perceive a disconnect between theoretical knowledge and real-world problems, or have limited opportunities for meaningful knowledge application. These conditions may, in turn, lead to lower academic performance, higher attrition rates, and decreased educational satisfaction (Hauzel et al., 2024). Educators and practitioners are therefore encouraged to adopt active learning approaches at an early stage of student learning, link module content to real-world contexts, and provide practical experience for students to apply theory.

2.2 Significance for engineering education

Understanding and developing beliefs, motivation, and identity is valuable, as they underpin both individual growth and broader engineering and social systems.

At the individual level, first, these competencies shape students' learning behaviours, including academic choices, persistence, and retention in engineering, decision-making processes, and behavioural intentions (Kramer et al., 2024; Al Kakoun, 2023).

Second, they enable engineering educators and practitioners to critically reflect on the roles they assume in supporting students' acquisition of engineering-related knowledge and consider what pedagogical practices most effectively foster active engagement in technical problem solving and self-directed learning (Jiang et al., 2024; Kramer et al., 2024; Pierrakos, 2025). Therefore, the competencies are important for educators and practitioners to create learning environments that strengthen persistence, agency, and long-term engagement in learning.

Third, these competencies shape how engineers see their roles within the engineering profession and demonstrate confidence that they perform effectively in engineering. Engineers with stronger autonomous motivation and positive beliefs in their performance are more likely to see themselves as capable and committed members of the engineering profession (Curtis et al., 2017; Godwin et al., 2016; Pierrakos et al., 2009; 2016; Stoup & Pierrakos, 2016).

From a social perspective, beliefs, motivation, and identity reflect the culture and norms of engineering education. They capture how values such as ethics, efficiency, or social responsibility are emphasised (or marginalised) within engineering programmes. As Berger et al. (2017) suggest, understanding these competencies of both students and educators helps reveal what kind of knowledge and practice are legitimised and valued in a department or society. This means that beliefs, motivation, and identity are not merely individual traits; they are shaped by institutional contexts and broader societal influences (Kramer et al., 2024). Consequently, they contribute to sustaining or transforming the dominant narratives of engineering, such as whether it is seen primarily as a technical discipline or as a profession that also carries ethical and societal responsibilities.

3 Forms of implementation

Students' learning beliefs, autonomous motivation, and learner identity have been extensively studied across educational stages, from secondary and vocational education to higher education, and in diverse learning contexts (Brown et al., 2015; Kramer et al., 2024; Morelock, 2017; Wijnia et al., 2024). Educators and practitioners can use intentional teaching methods, structured module design, and targeted support resources to support student development (Wijnia et al., 2024). Accordingly, this chapter highlights some specific active learning approaches, followed by practical examples of module design and supportive resources. It also discusses the challenges engineering educators and practitioners may encounter in cultivating students' motivation, beliefs, and identity.

3.1 Teaching methods

As stated previously, student learning gets strengthened through problem-solving, practice-oriented, interactive, and student-centred active learning methods. This section thus outlines instructional strategies, such as problem-based learning (PBL), project-based learning (PjBL), case-based learning (CBL), and design-based learning (DBL) approaches, that can be implemented in the classroom settings. This section starts with providing brief definitions of each approach and highlights key practices to support educators and practitioners.

Problem-based learning (PBL) involves students working in small groups to define and solve ill-structured, real-world problems (Kolmos et al., 2008). PBL enhances autonomous motivation and beliefs and fosters identity development when students have genuine choice over problem framing, and when teachers provide directive yet non-controlling support and normalise uncertainty in complex problem-solving practices (Kolmos et al., 2008).

Project-based learning (PjBL) involves projects through which students individually or collectively learn the core concepts and principles of a field (Kolmos et al., 2008). In PjBL, student motivation is supported when essential project elements, such as standards (scope, goals, and purpose), time (deadlines, milestones) and resources (persons, equipment, material, budget), are clearly justified by educators and practitioners. Within teams, students should be given the autonomy to decide

problem-solving routes, distribute tasks, and assume different team roles to complete projects. Students are more likely to develop a growth mindset when they engage in projects connected to real-world scenarios and apply knowledge in practice (Jiang et al., 2023), and when teachers simultaneously provide structured coaching through regular progress meetings and ongoing formative feedback (Pierrakos et al., 2024).

Case-based learning (CBL) uses cases to contextualise discipline- or practice-specific knowledge (Wijnia et al., 2024). However, students tend to report lower autonomous motivation and weaker beliefs when cases are used only as examples to complement lectures, with all information provided by teachers, all students working on the same case, and discussions led entirely by teachers. In contrast, co-creation approaches involving students, teachers, and relevant external stakeholders in authentic cases are found to promote student learning beliefs and ownership over learning (Lavi & Marti, 2023).

Design-based learning (DBL) focuses on the design process itself, and the designers' engagement with that process (Al Kakoun, 2023), by encouraging iterative prototyping, testing, and refinement, rather than solely focusing on the final product (Azizan & Abu Shamsi, 2022; Pierrakos et al., 2024). Students' autonomous motivation and beliefs are strengthened if students can empathise with users' needs, clearly identify problems based on those needs, and generate, test, and prototype tangible solutions.

In summary, these active teaching methods can be applied to individual module designs or systematically integrated across programmes or institutional strategies to support students' beliefs, motivation, and identity development (Chen et al., 2024; Pierrakos, 2025; Wijnia et al., 2024). Educators and practitioners can nonetheless draw on or combine key practices from these approaches, such as real-world problems, small-scale projects, authentic cases, collaboration with community partners and external stakeholders, or a structured design process to meaningfully inform and enrich their own teaching practices. Although the following section presents only the four approaches mentioned above as practical examples, other active learning strategies, such as the flipped classroom, collaborative learning, and experiential learning, may also effectively support student learning.

3.2 Practical examples for module design

This section presents two cases illustrating how these four active learning approaches can be integrated into module design to foster students' autonomous motivation, learning beliefs, and learner identity, as well as how educators and practitioners may assess these competencies. The cases are drawn from the authors' own teaching practices across different institutions and nations, including Aalborg University, Denmark, and Swansea University, UK.

Example 1. Problem-based learning (Aalborg University, Denmark)

Target group. *First-year engineering undergraduate students*

Active learning approaches used. *DBL, PBL, and PjBL*

Framework. *five stages of a design-based approach for teaching design*

Stages:

1. Empathise. *Students start with an ill-structured problem in their own field, develop contextual understanding, and consider the needs of key stakeholders.*
2. Define. *Students synthesise insights from the empathise phase to articulate a clear and actionable problem.*
3. Ideate. *Students apply divergent thinking and use appropriate tools or strategies to generate multiple solutions for the defined problems.*
4. Prototype. *Promising ideas are transformed into tangible prototypes, such as products, processes, or experiences, to test assumptions for further refinement*
5. Test. *Students gather feedback on their prototypes, evaluate results, and determine next steps.*

Module activities:

- Preparation. *Students access videos, slides, readings, and a toolbox on the university's Moodle platform to build foundational knowledge and understanding of problems (link to stages 1 and 2).*
- Workshops. *Students apply strategies and tools on problem design, project management, and team collaboration (link to stages 1 to 4).*
- Online consultation. *Students seek clarifications and guidance from teachers to select appropriate tools for project management, problem design, and team collaboration, if needed (link to stages 3 and 4).*
- Assignment. *Students submit group assignments (link to stage 4).*
- Portfolio. *Students document their learning process, reflect on the effectiveness of strategies used, and identify areas for improvement (link to stages 4 and 5).*
- Feedback. *Students receive rubric-based written feedback from teachers on both their assignment and portfolios (link to stages 4 and 5)*

Examples:

- Problem identification, analysis, and formulation. *Students use the 5W1H model (what, why, who, when, where, how) to identify problems. Students conduct literature reviews, stakeholder interviews and analysis, and fieldwork to analyse problems within real-world scenarios. Students also use the Pugh matrix, a criteria-based decision-making tool, to compare and evaluate multiple design options and identify the most suitable solution to the problems they have identified.*
- Project management. *students use a Work Breakdown Structure (WBS) to define clear project goals, milestones, and tasks. They apply critical path analysis to estimate project timelines and use tools such as Gantt charts and Scrum to maintain an overview of progress and support daily task management.*

The following tools are used for assessing students' motivation and beliefs development):

- *Qualitative content analysis of students' portfolios.*

Theoretically, this example reflects a motivation-centred theory lens, highlighting how students' beliefs and values about their learning shape their motivation and, over time, indirectly contribute to their identity development. In practice, students' motivation and learning beliefs in this module can be assessed at two points — mid-semester and at the end of the term — to track their development over time. Their beliefs and motivation are strengthened when they receive consistent rubric-based criteria and detailed written feedback, work with clear project goals, engage in hands-on workshops, collaboratively identify and solve problems grounded in stakeholder needs and fieldwork, and participate in structured reflections (Jiang et al., 2022, 2023). The staged design-based learning approach (empathise–define–ideate–prototype–test) further supports this development by combining structure with autonomy, enabling students to move from passive participation towards more active, collaborative, and self-directed learning.

More detailed information about practices at Aalborg University can be found in Chapter 4.2: Systems Approach to Transferable Skills in PBL-Based Engineering Education: The Aalborg University Case.

Example 2. Conceptual design: human-focussed design workshop, Swansea University, UK

Target group. *first-year and third-year civil engineering undergraduate students*

Active learning approaches used. *DBL and CBL*

Framework. *Communal Design lens within a human-centred designing assignment (DBL sequence)*

Stages

1. Surface learner dispositions (diagnostic phase). *Students complete disposition questionnaires before the design task that may influence their decision making and their ability to handle uncertainty.*
2. Orient to social impact and responsibility. *A guided class discussion frames how civil engineering designs shape quality of life and social responsibility, and invites students to reflect on privilege and real-life impacts to build empathy before designing.*
3. Contextualise and analyse the case (part A). *Students are shown a district in Beirut, Shatila, using plans, maps, structural information, occupation listings, and quality-of-life reports to identify how needs have been met or unmet, and how this appears in well-being indicators.*
4. Define unmet needs and propose a conceptual design (part B). *Students identify the physical and metaphysical needs of Shatila residents and propose a conceptual civil engineering design to improve their life quality. The task uses the Matrix of Human Needs and Satisfiers (Max-Neef et al., 1991), a framework that identifies how different practices meet fundamental human needs while reducing subjective bias of "satisfactory living" and avoiding hierarchical assumptions about human needs.*

5. Demonstrate communal design and reflect. *Interaction-oriented needs (Communal Design) are one evaluation criterion, referring to whether the design explicitly enables social interaction, identity, and togetherness beyond technical or basic physical needs. The design is qualitatively evaluated by two independent external referees, based on predefined criteria and cross-checking. Students' final outputs are then compared to their initial dispositions (of stage 1) to determine how personal dispositions relate to their design outcomes.*

Module activities:

- Preparation. *Students receive an information pack with Shatila maps and briefs, quality-of-life reports, and the Matrix for Human Needs and Satisfiers.*
- Workshop discussion. *Students engage in a facilitated discussion on social impact, social awareness, and responsibility in civil engineering.*
- Task delivery. *Students complete part A and B. No detailed design is required; the focus is on what needs and priorities students' foreground when designing for quality of life.*
- Empathy-building activity. *Students are shown pictures of Shatila residents carrying out daily tasks during their design assignment. The pictures are selected to support empathetic understanding of Shatila residents' regular living conditions and needs.*
- Post-task instruments. *After submitting solutions and designs, students complete a questionnaire pack capturing their social awareness and empathetic and prosocial indicators.*
- Evaluation. *Design outputs are coded as communal or non-communal designs based on criteria and activities in stage 5.*

Examples:

- Root-cause orientation and creative breadth. *Students are prompted to look for root problems rather than temporary fixes and to generate solutions that address multiple issues per concept, while repeatedly engaging in perspective taking (put yourself in the shoes of Shatila residents).*
- Communal design criteria (metaphysical and interaction needs). *Examples used as criteria include "living spaces/social environment/dwelling", "settings of participative interaction such as communities/neighbourhoods/family", and "privacy/intimacy/spaces of closeness".*

The following tools are used for assessing students' motivation, beliefs, and identity during the module (Al Kakoun, 2023; Al Kakoun, Boy, Groves, et al., 2021; Al Kakoun, Boy, & Xavier, 2021; Al Kakoun et al., 2024):

- Disposition questionnaire in stage 1. *Portrait Values Questionnaire-Revised (PVQ-RR) and Almost Perfect Scale-Revised (APS-R).*
- Empathy-building activity. *Interpersonal Reactivity Index (IRI).*
- Post-task instruments. *Self and Social Awareness Instrument, Prosocialness Scale for Adults; Prosocial Behavioural Intentions Scale.*

In this DBL- and CBL-oriented module, students' personal traits and underlying beliefs about social awareness, responsibility, and empathy influence how they exercise autonomous motivation and make decisions in uncertain, human-centred contexts. This example reflects a motivational-centred and integrative theories perspective, highlighting the dynamic interplay among the three competencies, showing how personal values and traits shape social awareness, empathy, and creativity in engineering problem solving and design. By engaging with the lived conditions of Shatila residents and developing empathy-informed, open-ended design processes, students are encouraged to move beyond purely technical or basic physical solutions. This process supports the development of a professional identity that integrates social responsiveness, ethical responsibility, and empathetic understanding into engineering practice. More detailed information about the Example 2 questionnaire results and module methodologies and practices can be found in (Al Kakoun, 2023; Al Kakoun, Boy, Groves, et al., 2021; Al Kakoun, Boy, & Xavier, 2021; Al Kakoun et al., 2024).

In summary, although these two examples show how active learning approaches could support students' beliefs, motivation, and identity development, educators and practitioners who adopt traditional lecture-based teaching can also draw valuable insights. By linking core concepts to real-world practices (e.g. stakeholder analysis, root-cause thinking, or contrasting community contexts), educators and practitioners can highlight the social impact of engineering and portray engineers as both technical experts and socially responsible professionals. In addition, integrating brief reflective prompts, clear rubrics, written feedback, or case-based illustrations can further strengthen students' beliefs and motivation without fundamentally altering the teaching format.

3.3 Challenges in developing beliefs, motivation, and identity

First-year undergraduate engineering students often begin higher education with beliefs shaped by their earlier schooling experiences, which may not align with student-centred pedagogies. For example, some may equate learning with memorising facts or view the teacher as the sole source of knowledge. These beliefs can limit their willingness to engage in active, student-centred approaches such as PBL, PjBL, DBL, or CBL, where students are expected to construct knowledge collaboratively and independently (Wijnia et al., 2024).

A further challenge is sustaining students' motivation and beliefs throughout extended learning processes. Such challenges often arise when students find a topic initially engaging but their motivation can quickly decline once the novelty wears off. In longer projects, motivation and learning beliefs may weaken further if students fail to see tangible progress, if tasks become repetitive and lack variety, or if the content feels less relevant (Cech, 2010). This issue is especially evident in engineering and project-based contexts, where the iterative nature of design and problem solving can sometimes lead to frustration (Jiang et al., 2022).

When students work in a group to deliver designs or projects, team dynamics can undermine students' motivation and beliefs as communication barriers, cultural

misunderstandings, and unequal participation emerge. Such challenges often lead to frustration, reduced trust, and doubts about the value of collaboration. Conflicts and differing expectations within teams may lower students' self-efficacy and weaken their beliefs in the effectiveness of group work, while also diminishing intrinsic motivation to engage fully in the learning process (Jiang, Dahl, & Du, 2023).

4 Recommendations for implementation and learning

Drawing on earlier sections covering definitions, relevant theories, arguments, and forms of implementation, this chapter proposes several key recommendations for engineering educators and practitioners.

First, embrace a holistic view on autonomous motivation, learning beliefs, and learner identity. We summarize existing theories in three aspects: motivational-centred, identity development, and integrative theories to better understand their interconnectedness. Each lens can inform teaching design and guide the educators and practitioners to understand and measure these three competencies as developing over time (longitudinally), as structured in relation to one another (hierarchically), or as dynamically influencing each other (reciprocally).

Second, empower students to take responsibility for their learning. Autonomous motivation and learning beliefs grow when students can self-direct their learning by exploring real-world problems, choosing project topics, and identifying relevant learning content. High-impact practices like DBL, CBL, PBL, and PjBL support these processes while addressing both personal and societal needs. Meanwhile, teachers should serve as facilitators rather than learning controllers, supporting students to make meaningful choices, encouraging facilitation-based dialogues, set up learning goals, and understand mutual expectations.

Third, create authentic problems, challenges, and cases. Based on the learning principles of PBL, PjBL, CBL and DBL, it is essential that the problem or challenge aligns clearly with the module's learning objectives while being situated in a meaningful real-world context. Authentic problems should be connected to community partners, industry needs, or broader societal challenges. They should encourage student learning beyond the classroom through external collaboration with community, industry, or other organisations. Identifying and addressing real-world challenges also calls for educators and practitioners to structure modules in staged learning phases, enabling students to progressively develop motivation, beliefs, and identity.

Fourth, provide opportunities for self-reflection. Drawing on case 1, students should regularly reflect on their learning through tools such as learning portfolios, reflective journals, structured debriefing or in-class check-ins, enabling them to understand the three competencies as developing over time, structured in relation to one another, and dynamically interacting. A structured reflective loop, examining what, how, and why they learn, helps them connect current learning to future development and their careers (Gibbs, 1988). Constructive and structured feedback is essential for students

to track their learning progression, refine strategies, and strengthen beliefs and motivations.

Fifth, build learning communities. Students learn best in an inclusive environment where they can exchange ideas, co-create meanings, and build their identities within supportive peer networks. Teamwork or group-based assignments could benefit students by creating space for co-learning and develop learning beliefs and motivation.

Sixth, highlight social awareness and responsibility. Inspired from both cases, educators and practitioners should integrate socially grounded examples and empathy-informed, community-connected challenges to strengthen engineering identity, positioning engineers not only as technical problem solvers, but as socially responsive professionals.

Lastly, if you want to deepen your knowledge, we want to recommend the following resources in addition to the literature cited in this chapter: Elliot et al. (2017) and Murray et al. (2011).

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AI statement

During the preparation of this work, the authors used ChatGPT in order to correct grammatical errors and improve sentence clarity and coherence. After using this tool, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

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Initiative and Perseverance in Engineering Education

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This chapter examines initiative and perseverance as essential but often underdeveloped competencies in engineering education. Initiative refers to self-starting and proactive behaviour, while perseverance is the ability to sustain effort in the face of setbacks, uncertainty, and failure. Using self-regulated learning as a framework, we describe how these qualities develop through cycles of planning, action, monitoring, and reflection. We also draw on studies of perfectionism to demonstrate how personal motivations and traits influence students' ability to act and persist in their academic pursuits. Engineering education culture, characterised by heavy workloads, rigid grading, time pressures, and perfectionist expectations, creates conditions that can both encourage and hinder these qualities. Case studies demonstrate how active and experiential pedagogies, combined with reflective practice, offer students opportunities to develop initiative and perseverance. We recommend that educators create feedback-rich, autonomy-supportive environments, while ensuring that their modules and interventions align with students' personal motivators and mitigate perfectionist tendencies. By combining cultural, personal, and pedagogical perspectives, engineering education can better prepare students to become adaptable and resilient engineers who are able to meet uncertainty with creativity and persistence.

1 Definition

In this chapter, initiative and perseverance refer to engineering students' ability to independently make rational decisions and solve problems in their academic programmes and personal lives. Nowadays, it is increasingly critical for engineering students to skilfully handle unpredictable and disruptive events that are often out of their control; devise new strategies to address complex, interdisciplinary engineering problems; and achieve their goals in a constantly evolving academic and career landscape (Jonassen et al., 2006; National Academies of Science, Engineering, and Medicine, 2017). Over time, students can develop initiative and perseverance in response to the conditions and disruptions imposed by their personal and academic environment (Gesun et al., 2021). We also connect initiative and perseverance to self-regulated learning and perfectionism to discuss some of the complex mechanisms that reinforce or undermine these competencies.

1.1 Defining initiative

According to Frese and Fay (2001), the concept of 'personal initiative' manifests in the workplace through three key behaviours: being self-starting, proactive, and persistent. Self-starting involves taking control of situations without external prompting, proactive behaviour requires anticipating and adequately preparing for potential future events, while persistence ensures that goals and plans are successfully executed. Effective initiative arguably requires openness to change, new ideas, experiences, and growth (Birkinshaw, 1999) and a willingness to take risks (Highhouse et al., 2022). In contrast, individuals lacking initiative display passive and reactive behaviours, waiting for instructions, information, and assistance rather than seeking them independently.

1.2 Defining perseverance

Table 2.18.1: Definitions of grit, growth mindset, and resilience

<i>Term</i>	<i>Definition</i>
Grit	The ability to work strenuously toward challenges, maintaining effort and interest over years despite failure, adversity, and plateaus in progress. It consists of passion and perseverance for long-term goals (Duckworth et al., 2007).
Growth mindset	The belief that intelligence and ability are malleable (Dweck & Legget, 1998; Dweck & Yeager, 2019).
Academic resilience	The ability to effectively deal with setbacks, challenges, adversity, and pressure in academic settings (Martin & Marsh, 2006).

Perseverance, a synonym for persistence, complements initiative. It refers to students' unwavering resolve in the face of challenges and setbacks during their academic journey, including learning complex concepts, performing poorly on an assessment,

or failing an engineering module (American Psychological Association, 2023; Cambridge University Press, n.d.). Perseverance is closely related to grit, a growth mindset, and resilience — concepts that have been extensively studied in engineering education (Table 2.18.1). Together, these concepts suggest that the key to skilfully navigating disappointments and unfavourable circumstances is a positive, long-term outlook.

1.3 Self-regulated learning

Self-regulated learning (SRL) theory (Bandura, 1986; Pintrich 2000) connects desired observable behaviours (e.g., initiative and perseverance) to internal learning mechanisms. At the individual level, SRL operationalizes learning as a continuous process with three phases: (1) forethought, (2) performance; and (3) self-reflection. In the forethought phase, students set goals and make strategic plans based on their motivational beliefs. The next phase, performance, is characterized by task execution. For example, students can control and observe their behaviour towards academic tasks in real-time by focusing their attention, employing time management strategies, and seeking help. In the final phase, self-reflection, students evaluate their performance, revise their goals as required, and prepare for future tasks. In collaborative settings, SRL can occur simultaneously at the individual and group levels, as shown in Fig. 2.18.1 (Hadwin et al., 2018; Panadero, 2017).

SRL presents learning as an active, student-driven exercise. A key assumption of SRL theory is that students will act to achieve their goals (Pintrich, 2000). However, not all goals are necessarily focused on learning. Students may be motivated to develop competence (i.e., mastery goal orientation), or they may desire to appear competent relative to their peers (i.e., performance goal orientation) (Pintrich, 2000). These orientations determine whether students approach or avoid academic tasks (Table 2.18.2).

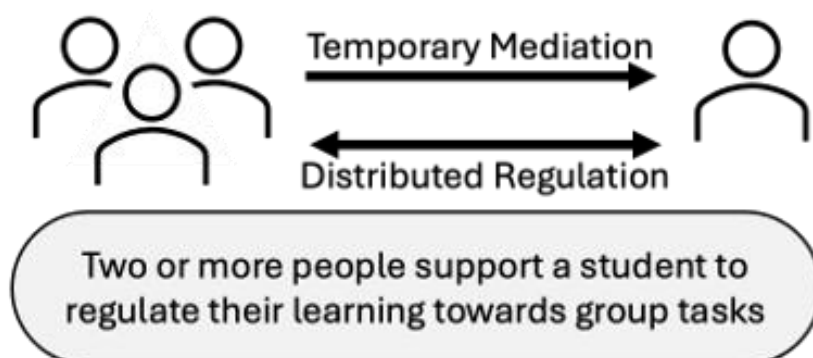
Table 2.18.2: Mastery and performance goal orientations (adapted from Pintrich, 2000)

	<i>Mastery goal orientation</i>	<i>Performance goal orientation</i>
Approach	Seeks to promote deep understanding and skill acquisition	Seeks to feel superior and appear competent
Avoidance	Seeks to avoid a loss of knowledge and skills	Seeks to avoid feeling inferior and appear incompetent

1. SRL in collaboration



2. Coregulated learning (Co-RL) in collaboration



3. Socially shared regulation of learning (SSRL) in collaboration

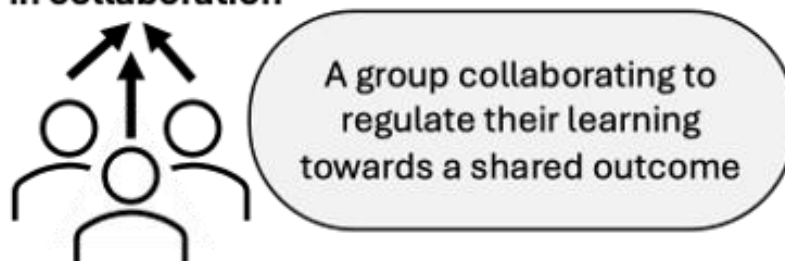


*Figure 2.18.1: SRL in collaborative settings
(Own Work by authors)*

We are not the first authors to connect initiative, perseverance, and SRL (Frese & Fay, 2001). In Table 2.18.3 the 'action sequences' of personal initiative echo the phases of SRL. Thus, we posit that the relationship between SRL, initiative, and perseverance is reciprocal. Students require initiative and perseverance to make decisions and take ownership of their academic development (i.e., plan, execute, and evaluate their performance). Similarly, by continuously engaging in the SRL process, they will deepen their capacity to actively and proactively take initiative and persevere over time.

Table 2.18.3: Facets of personal initiative (adapted from Frese & Fay, 2001)

<i>Action sequence</i>	<i>Self-starting</i>	<i>Proactive</i>	<i>Overcoming barriers</i>
<i>Goal development</i>	Set and redefine goals	Anticipate problems and opportunities	Protect goals from interference (e.g., frustration)
<i>Information collection and prognosis</i>	Actively search and find information	Consider potential problems, opportunities, and alternatives	Maintain search despite complex, negative emotions
<i>Plan development and execution</i>	Actively plan	Have back-up plans and action plans for unplanned opportunities	Overcome barriers; return to plan quickly when disturbed
<i>Monitoring and feedback control</i>	Self-developed checks and feedback	Develop alerts for potential problems and opportunities	Protect feedback from interference (e.g., unclear assignment rubrics, miscommunication)

1.4 Perfectionism

Perfectionism, a psychological trait characterized by setting high goals, expectations, and standards for oneself and/or others (Hewitt et al., 1991; Slaney et al., 2001), also affects student motivation. When high expectations are accompanied by harsh and overly critical self-evaluations and self-doubt, this can be considered unhealthy or 'maladaptive' perfectionism (Hewitt et al., 1991; Slaney et al., 2001). Maladaptive perfectionism is highly associated with how students choose to engage with engineering academic tasks, especially those that are explorative, non-computational, or ambiguous in nature (Al Kakoun, 2023; 2024). In such tasks, students' fears and/or anxiety of not being able to achieve said high standards are triggered, which would then lead to task avoidance (Weiner & Carton, 2012). Such a trait is thought to impact students' motivation, initiative, and/or perseverance in engaging with highly complex, ambiguous, explorative engineering education or practice. From an educator's perspective, it could provide a way to rationalize students' subconscious choices, behaviours, and reactions.

Furthermore, perfectionism appears to significantly influence initiative-taking behaviours, though its impact varies by type. Maladaptive perfectionism manifests as avoidant behaviour and risk aversion (Jia et al., 2025), and demonstrates strong inverse relationships with openness, divergent thinking (Al Kakoun et al., 2024; Goulet-Pelletier et al., 2025), and cognitive flexibility (Akkuş Çutuk, 2020), while correlating positively with cognitive rigidity (Ferrari & Mautz, 1997). In contrast, positive perfectionism enhances innovation by promoting mastery-oriented learning

and experimentation (Jia et al., 2025). In addition, Leung et al. (2019) found that tolerance of ambiguity is positively associated with adaptive perfectionism but negatively associated with maladaptive perfectionism. Thus, maladaptive perfectionism undermines SRL.

In summary, we introduced initiative and perseverance as essential skills for academic and career success and used SRL to understand how motivation and perfectionism may promote (or hinder) their development in students. The following section presents findings investigating initiative, perseverance, and related concepts in engineering students and practitioners. In particular, we discuss the effect of the perfectionist mindset, engineering culture, and pedagogical decisions on students' ability to persist and take initiative.

2 Why teach initiative and perseverance competencies

Whether facing academic challenges, professional setbacks, or technical obstacles, successful engineers must proactively identify opportunities, initiate action without external prompting, and persist through failures and uncertainties. Yet, despite the industry's clear valuation of these competencies, they remain largely absent from formal engineering curricula, being neither explicitly taught nor systematically assessed (Jonassen et al., 2006). This pedagogical gap leaves students unprepared for the realities of engineering practice.

2.1 Engineering careers require initiative

While initiative has received extensive attention in psychology and entrepreneurship research, engineering education has only begun to explore this critical competency. Industry consistently signals the importance of initiative for engineering practice. Engineers face ill-defined, complex problems requiring evidence-based, pragmatic solutions — work that necessitates technical knowledge, resourcefulness, adaptability, and determination (Godfrey & Parker, 2010; Passow & Passow, 2017; Winberg et al., 2018). As a result, companies desire entry-level engineers who possess initiative-related competencies and demonstrate forward-thinking and proactive behaviours such as 'stepping up' and 'going that extra step', as well as self-confidence and leadership (Hartmann & Jähren, 2015; Passow & Passow, 2017, Syal et al., 2020).

Taking initiative requires people to be open to change. Concerningly, however, engineering students' ability to do so appears to be declining over time (Al Kakoun, 2021, 2023), potentially undermining their capacity for initiative. These interconnected competencies — initiative and openness — are essential for contemporary engineering practice.

2.2 Engineering careers require perseverance

Engineering students need perseverance to complete an engineering degree. Graduation rates, one well-documented method of observing engineering student persistence, refers to students' ability to graduate from their engineering programme without changing majors or dropping out of university (Seymour & Hunter, 2019; Susan et al., 2019). A significant proportion of engineering education research is

devoted to improving the graduation and attrition rates of engineering students, especially those who belong to historically marginalized groups within engineering. Students are more likely to persist and overcome challenges when they have strong interests in their engineering discipline, positive self-efficacy beliefs, are willing to ask for help and open to feedback, and have a strong support system (Hunsu et al., 2021; Seymour & Hunter, 2019; Washington & Momdisa, 2021). As an illustration, Hunsu et al. (2021) examined the resilience of three categories of students who failed the first exam in a foundational engineering module. The students who improved academically consistently demonstrated higher resilience than those who did not improve and those who dropped the class after the first exam. Therefore, students' ability to persevere in engineering programmes is influenced by personal, programmatic, and institutional factors.

Grit, often described as a combination of passion (interest) and perseverance (effort), is another method of observing engineering students' ability to persevere. It is a relatively new area of research in engineering education, so its impact on engineering students' academic outcomes (e.g., persistence in the discipline) remains unclear (Direito et al., 2019; Duckworth et al., 2007). In engineering education, it has been assessed using Duckworth's Grit scale, interviews, open-ended survey questions, students' journal entries, and observations (Direito et al., 2019). Current results show that engineering students tend to think about grit in terms of 'working hard', being 'resilient', and having 'short-term motivation'; younger students have more grit compared to older students; and women are 'grittier' than men (Direito et al., 2019). These results suggest that engineering students have a limited view of grit that prioritizes effort or hard work over 'passion'. In addition, the ability to persevere is not fixed but varies across different student groups and likely changes over time.

2.3 Perfectionism and engineering culture

The prevailing attitudes toward academic achievement in engineering education profoundly influence how students approach creativity, risk-taking, and failure. Engineering modules are notorious for low grades, norm-referenced grading practices, demanding coursework, high assignment volumes, and often misaligned teaching methods (Deteres et. al, 2024; Jensen et al., 2023; Seymour & Hunter, 2019). While students may bond over challenging circumstances (Godfrey & Parker, 2010), these experiences can undermine the persistence of students who do not find a community within their engineering contexts. In the United States educational system, women and historically minoritized students face additional experiences of negative stereotypes and isolation in engineering education (Jenson & Cross, 2021; Seymour & Hunter, 2019). The importance of peer networks in supporting the persistence of engineering students is well-documented (Jensen et al., 2023; Seymour & Hunter, 2019). Furthermore, the high stress and poor health outcomes endemic to engineering education further compromise students' ability to persist (Jensen and Cross, 2021; Seymour & Hunter, 2019).

2.4 Perfectionism as a fixed mindset

Within this culture of difficulty, maladaptive perfectionism emerges as a particularly problematic mindset. Students may view mistakes and failures as measures of ability instead of learning opportunities (Deck & Yeager, 2019). Additionally, they may be more concerned with defending their intelligence rather than developing their competencies and skills over time, which hinders their ability to take initiative. Perfectionism can be assessed using instruments such as the Revised Almost Perfect Scale (Slaney et al., 2001) and the Multidimensional Perfectionism Scale (Hewitt et al., 1991).

Highly prevalent among engineering students, perfectionism creates specific vulnerabilities for high achievers (Al Kakoun, 2023; Al Kakoun et al., 2024). 'Effortless perfectionism', i.e., the belief that true ability means earning good grades with minimal effort or assistance, transforms academic struggle into an identity crisis. Students who tie their self-worth to effortless achievement interpret lower grades despite hard work as evidence that they do not belong in engineering (Dringenberg et al., 2022). Students embracing this performance-avoidance orientation struggle with challenging tasks and avoid risks, whereas mastery-oriented students of similar ability adaptively seek challenges and transform setbacks into learning opportunities. Stevens et al. (2007) documented how these meritocratic attitudes create persistent insecurity about abilities. Thus, a perfectionist mindset undermines the persistence of otherwise capable students.

2.5 Pedagogical considerations

In the classroom, teaching practices, assessment methods, and pedagogical choices translate faculty's beliefs into educational experiences (Godfrey & Parker, 2010). These practices directly shape students' opportunities to develop initiative and perseverance. In particular, the interaction between students' mindsets, engineering culture, and pedagogical choices creates barriers to developing initiative and perseverance. Educators who view initiative and perseverance as inherent traits (Seymour & Hunter, 2019) or cultivating them in students as outside the scope of technical engineering content (Godfrey & Parker, 2010) are less likely to design learning opportunities targeting their development in students. Typically, students encounter these professional skills peripherally, in isolated professional development modules or end-of-semester capstone projects, which limits their meaningful application to ongoing academic and personal development.

In addition, the preference of content delivery through lecture-based instruction over student-centred pedagogy (Seymour & Hunter, 2019) denies students opportunities to take ownership of their learning through creation, reflection, decision making, and iterative practice (Sukacké et al., 2022). The focus of engineering education on quantifiable outcomes, such as exam grades and grade point averages (GPAs), inadvertently excludes difficult-to-measure but crucial competencies, like perseverance and initiative, despite their importance for holistic development (Gesun et al., 2021; Godfrey & Parker, 2010).

Moreover, decontextualized teaching of engineering principles (i.e., prioritizing formulas and derivations while omitting sustainability, societal impact, and historical context) misses crucial motivational opportunities for learning (Godfrey & Parker, 2010). By stripping away the people, processes, and circumstances behind engineering knowledge, educators miss opportunities to demonstrate how previous generations of engineers persevered through challenges, learned from mistakes, and took initiative toward innovation.

Finally, students' experiences inside and outside the classroom also impact their ability to persevere. Many scholars have documented how the meritocracy of difficulty within engineering education normalizes struggle while attributing success solely to individual factors, obscuring the impact of social inequalities and access to resources (Cech, 2013; Deters et al., 2024; Godfrey & Parker, 2010; Stevens et al., 2007). Similarly, one of the main criticisms of grit is that it perpetuates systematic inequalities by overlooking the effect of the environment on individual success (Direito et al., 2019). In a recent study, Deters et al. (2024) observed a misalignment between some instructors' expectations and the realities of online learning during the COVID-19 pandemic, demonstrating how different levels of access to a distraction-free home environment and reliable technologies (e.g., internet connectivity) resulted in unequitable learning experiences. These findings illustrate how contextual factors outside of engineering modules impact individual students' ability to persist and ultimately succeed.

2.6 Implications for engineering education

Addressing these challenges requires fundamental shifts: viewing competencies as malleable rather than fixed, creating scaffolded opportunities throughout the curriculum, implementing assessment methods that value process alongside product, and providing time and space for meaningful engagement with complex problems. For example, open-ended problem-solving pedagogies, including project-based learning, problem-based learning, and inquiry-based learning, naturally cultivate initiative and perseverance by emphasizing the process over the product. These methods align with engineering practice, where outcomes depend on creative and technical decision making (Smith et al., 2013; Sukacké et al., 2022). Only through deliberate interventions can engineering education cultivate the initiative and perseverance that professional practice demands. In the next section, we present and discuss different case studies that illustrate these methods.

3 Forms of implementation

In the previous sections, we argued that initiative and perseverance competencies can change over time. Therefore, creating multiple, scaffolded opportunities for students to practice, receive feedback, and refine these skills throughout their education may prove beneficial. While research in this area continues to evolve, we suggest that engineering educators may develop students' initiative and perseverance through two complementary approaches: implementing authentic learning experiences that reflect the complex nature of engineering problem solving (Sukacké et al., 2022), and (re)designing authentic learning environments. By creating opportunities for students to continuously practice proactive and reflexive academic behaviours, guided by peer and instructor feedback, these two approaches reinforce self-regulated learning mechanisms required to develop initiative and perseverance. In the following section, we present a few case studies that range from simple, ungraded assignments to more complex projects and module redesign efforts. With careful consideration for the local context, these examples can be implemented either in spirit or in letter in different contexts. We also hope that they inspire new and creative possibilities.

3.1 *Learning experiences that promote initiative and perseverance*

Authentic learning experiences, such as capstone design, laboratory modules, undergraduate research, and project-based learning, can foster motivation, thus enabling persistence and initiative-taking. For example, participating in a community service project increased the perseverance of STEM students at a Hong Kong secondary school in solving problems and completing tasks (Nalipay et al., 2024). Another example that targets student motivation is an ungraded cover letter assessment (Example 1) that develops persuasive communication skills students need to navigate professional opportunities (Allen & Pierce-Cottler, 2008). In writing the letters, students reflected on their current abilities, interests, and future career goals. Furthermore, the interactive weekly discussions encouraged students to take ownership of their project as they delivered updates, sought help, and received feedback. To support student persistence, instructors anticipated potential problems in advance and provided students with weekly advice to proactively address them. In addition, by requesting students to provide frequent updates and act on feedback, this practice also addresses unhelpful perfectionist tendencies.

Example 1. Promoting student responsibility and professional development in a capstone module (Allen & Pierce-Cottler, 2008)

This mandatory, undergraduate capstone design module was conducted over two semesters in the final year of the program.

Matching process

First, students received a list of potential capstone projects that summarized the project's needs and expectations. Then, the engineering department hosted a project fair to connect clients and students. Students could also submit their own project if it aligned with the module's learning objectives. Afterwards, students

applied to a few projects, describing how each project aligned with their qualifications and future career goals. Then, instructors matched the students and clients based on mutual preferences.

Learning process

- *Each week, a few teams presented progress updates and received feedback from peers and instructors.*
- *Students received weekly emails summarizing important professional tips (e.g., "How to ask questions when one is trying to learn about a project?").*
- *Guest lectures and workshops covered a range of professional topics.*
- *In addition to oral and written reports, students were evaluated on their ability to regularly communicate with the client and demonstrate resourcefulness (i.e., being proactive).*

Example 2 is an engineering module designed to help students 'learn from failure' (Winkens et al., 2024). This approach increased students' personal and social-technical resilience competencies. In the reflective journals, students frequently reflected on their academic struggles (e.g., conducting literature reviews), conceptual changes (e.g., defining resilience vs. risk analysis), and how to incorporate resilience (e.g., flexibility, adaptability, and preparedness) into their future careers. Therefore, the reflection activities helped students develop personal resilience and also deepened their conceptual understanding of resilience for sociotechnical systems. This example illustrates how initiative and perseverance can be presented alongside technical content in engineering courses to deepen students' conceptual understanding.

Example 2. Teaching resilience (Winkens et al., 2024)

This elective module for master students in engineering uses case studies to develop resilience thinking and the ability to analyse and plan resilient sociotechnical engineering systems. Each group identified a real-world or existing system, defined its boundaries, and assessed its resilience against plausible future uncertainties and disruptions or crises, using scenario planning and resilience analysis. The module assessments included:

- *Regular reflective assignments in the form of journals documenting students' learning progress, written in response to provided prompts such as "How did you learn from what happened?"*
- *a midterm recorded presentation, after which the students received peer and instructor feedback;*
- *a final report that documented the collaboration, justified group decisions, and responded to peer feedback.*

These two examples illustrate how instructors can develop creativity and endurance in engineering students by creating opportunities for them to make decisions and take ownership of their educational experiences (e.g., goal-directed behaviour), requiring them to document their process to make their learning visible, and building in periodic

check-in points to encourage reflection, help-seeking, and strategic planning towards their identified goals. Further, allowing them to make choices and well-designed authentic learning activities, such as cover letters and collaborative (peer) learning, increases student engagement. When implementing these types of assessments, the instructions and evaluation methods must be clear and transparent to minimize bias.

3.2 Interventions that promote perseverance

Bahnson et al. (2025) implemented a brief ecological belonging intervention — that is, performed with the whole class, within the classroom environment, at the same time — in a large first-year engineering module with historically persistent performance gaps across student demographics. In general, the intervention improved the students' module grades and continued enrolment in engineering. In particular, the intervention had a significant impact on the sense of belonging among women in the class and the module grades of students from historically minoritized populations, such as Black, Latinx, and Indigenous students. These results demonstrate the effect of a simple intervention on enhancing engineering students' sense of belonging and their ability to overcome academic challenges.

Example 3. A module-specific intervention to encourage persistence (Bahnson et al., 2025)

This brief (ca. 45 mins) intervention, implemented for first-year students in the first week of class, encouraged students to expect setbacks and obstacles as a normal part of the learning process and proactively shared strategies to address them. During class, students reflected on, shared, and heard from others about their experiences when overcoming challenges. During the intervention, the facilitator — i.e., module instructor or teaching assistant — led the class in the following activities:

- *The facilitator discussed common issues students face, such as feeling homesick as a first-year student;*
- *students individually reflected on a current challenging situation and considered how they resolved or will resolve it;*
- *the facilitator presented stories from students who recently completed the module, describing how they overcame the challenges they experienced in the module;*
- *students discussed these solutions first in small groups and then with a whole class.*

3.3 Learning environments that promote initiative and perseverance

Creating authentic learning environments extends beyond individual activities. It involves rethinking the underlying philosophy of a module and making pedagogical decisions that are well-aligned with it. To this end, Talbert and Clark (2023) proposed four pillars of alternative assessments: 'clearly defined standards', 'helpful feedback', 'marks that indicate progress', and 'reassessments without penalty'. Example 4 demonstrates how feedback and reassessments can be effectively integrated into

engineering courses to foster initiative and persistence, thus enhancing academic performance (Morphew et al., 2019). Reassessments with feedback can direct students to take proactive steps towards improving their understanding. Instead of penalizing early mistakes and gaps, which are a normal part of the initial learning process, they reward students' persistence and effort towards achieving their academic goals.

Example 4. Building in feedback and reassessments into an engineering module (Morphew et al., 2019)

In the traditional schedule, students took two 'high stakes' midterm exams. Instead, the instructors of a large introductory engineering module implemented an alternative assessment schedule consisting of five open-ended lecture quizzes, seven computer-based exams, and a final exam. Students received feedback on the lecture quizzes after one week and the computer-based exams during and after each exam. During the exam, students could immediately retry incorrect solutions for reduced credit — time permitting — or they could choose to reattempt the (altered) exam in the following week.

Morphew et al. (2019) compared students' performance on the same final exam across two semesters, comparing the traditional schedule with the alternative schedule. Students with frequent exams performed better on the final exam ($M = 83.6$, $SD = 13.0$) compared to their peers in the traditional setup ($M = 76.7$, $SD = 14.0$). Relative to the traditional setup, fewer students failed and more students earned the highest grade in the alternative setup. To simplify the logistics of (re)assessment, the computer-based exams were administered outside of class through a testing centre, allowing students to take the exams at their convenience. Also, to make this system more manageable for students, the number of questions on the computer-based exams was significantly reduced relative to the traditional midterm exams. In general, assessment reattempts are more manageable in smaller classes, with 100 or fewer students (Talbert & Clark, 2023).

4 Recommendations for implementation and learning

We started this chapter introducing initiative and perseverance as essential skills engineering students need to navigate uncertainty and difficulty in their academics, careers, and life. As we discussed, because these skills are malleable and subject to change, engineering instructors can design academic activities and environments to help students develop them. In this section, we briefly share some practical recommendations based on the examples from the previous section. As you design learning activities and modules, we recommend:

Create opportunities for students to take ownership of their learning, which include:

- Offering options (e.g., students can select and apply to different capstone projects);

- Building flexibility into your module design (e.g., students can retake exams to improve their performance after receiving feedback);
- Setting up informal check-ins and progress reports with individual students or groups; for example, students can present a project update in which they explain their decision-making process and propose next steps.

Set healthy expectations for success, normalize failure especially early in the learning process, and encourage risk-taking behaviours. Working on open-ended engineering problems and community-engaged projects without clear-cut solutions is a great way for students to learn to grapple with uncertainty, manage timelines, work with others in a team, and manage different stakeholders' expectations. Students should be exposed to these types of problems throughout the curriculum, not only in capstone modules, so they can practice and build confidence in handling these types of unstructured problems.

Use reflection as a pedagogical tool for students to learn from previous mistakes and plan for the future. In Section 3, we shared how reflection activities were used to help students proactively think about their future goals, monitor their progress, and discuss their academic struggles. Reflection activities range from individual to group activities and graded to ungraded, informal activities. In addition to reflecting on their mistakes, students need an opportunity to demonstrate that they are making progress towards their goals.

Frequently give actionable and clear formative feedback to students, especially early on in their learning process. In addition, formally and informally evaluate students on their abilities to take initiative and persevere (e.g., resourcefulness, asking for help, incorporating feedback), in addition to technical engineering content. If you want to formally or informally evaluate student initiative and perseverance in your class, we recommend:

- Defining what resilience and perseverance look like in your context;
- Considering how you will observe, see, or measure resilience and/or perseverance;
- Consider how will you give students feedback;
- Consider how will you communicate your expectations with them;
- Anticipate the problems students are likely to encounter in advance and providing support systems and making resources available to students when they need it most.

In addition, we recommend increasing collaboration with various stakeholders to promote students' development of intrapersonal competencies, such as initiative and perseverance, through interdepartmental partnerships across modules, community and client partnerships, and by upper-level undergraduate and graduate students.

Finally, in addition to the literature cited in this chapter, we recommend the following literature to deepen your knowledge: Clark & Talbert (2023) and their guide to alternative grading practices and *Understanding by design* by Wiggins & McTighe (2025).

In summary, we recommend intentionally making space and time for students to develop initiative and perseverance in individual modules and throughout the curriculum, especially through activities that require strategic planning, reflection, and incorporating feedback. These types of strategies can give students a deeper appreciation for learning as an experimental process, full of risk and reward, that takes time and effort to eventually achieve desired results. Thus, they are prepared to productively engage with the ups, downs, and ambiguity that form a normal part of learning and life.

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2.19

From Evidence to Practice: Transferable Competencies and Skills in Engineering Education

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This chapter synthesises the transferable competencies and skills addressed in Part 2 and reframes them from a systemic perspective to contextualise their progressive development within modules, as part of curriculum development and across programmes in engineering education. It argues that competencies and skills are rooted in modules but best developed progressively. It identifies cross-cutting themes such as scaffolding, authentic learning, reflection, feedback literacy, interpersonal collaboration, and the critical use of technology, and discusses overlaps between skills, contextual sensitivity, and tensions between standardisation and individual adaptation. By making transversal structures explicit, the chapter positions Part 2 as a toolbox for module design, curriculum development, programme coherence, and institutional alignment. Finally, it prepares educators for the assessment focus of Part 3 by highlighting how intentional, contextualised skills development needs to align teaching practices and assessment with intended learning outcomes in engineering education.

1 Conceptual foundation and aim of this chapter

This handbook intends to give you evidence-based practical guidance for integrating transferable competencies and skills into your teaching practice. However, developing competencies and skills is not trivial. Unlike building a body of knowledge in students and teaching them to apply predefined methods, competency and skill development is shaped by our understanding of the concept itself. It makes a difference whether we focus on performances or dispositions, and whether we incorporate cultural, historical, or regulatory aspects into our practice.

Part 1 elaborated that terms such as *competence*, *competency*, and *skill* carry conceptual weight and have normative implications. These aspects are not merely an intellectual exercise. Instead, they have direct implications for educational practice. They tell us how intended learning outcomes are phrased, and how assessment is conceptualised with reference to a given institutional context or established frameworks.

In this respect, this chapter builds on Part 1, taking these insights as the foundation for reflecting on the chapters in Part 2, which address individual transferable competencies and skills and are grounded in these conceptual assumptions. Part 2 moves from that conceptual level to the practical yet complex reality of transferable competencies and skills in engineering education. The individual chapters each define and describe competencies and skills within different educational contexts, providing you with inspiration on how to shape your own practice, giving you food for thought, and, hopefully, stimulating you to discover new points of view. The goal of this reflection, however, is not to summarise each chapter in turn or repeat what has been laid out in more detail for each skill. Instead, we want to take a step back and look at the bigger picture by discussing the following questions:

- How can the chapters individually and collectively deepen our understanding of transferable competencies and skills in engineering education?
- Which intersecting themes and tensions run across the chapters of Part 2?
- What to take forward to Part 3, whilst thinking about assessment?
- In what way do individual competencies and skills relate to curriculum development, programme level change, and institutional transformation?

In short, this reflection acts as a bridge. It builds on the conceptual foundations of Part 1 and connects them with the concrete practices of Part 2, while also paving the way towards the assessment focus that follows.

2 Connecting individual transferable competencies and skills

Part 2 has been structured around three thematic clusters that are derived from the Engineering Council's (2020) UK Standard for Professional Engineering Competence and Commitment (UK-SPEC). These clusters reflect core areas of professional formation that are also widely recognised across European engineering education and accreditation frameworks, including the Engineering Education (ENAE) EUR-ACE

learning outcomes, the Engineers Europe EUR ING standard, and the European Qualifications Framework (EQF):

- Theme I. Responsibility, project management, and leadership (Chapters 2.2 – 2.5);
- Theme II. Communication and interpersonal skills (Chapters 2.6 – 2.12);
- Theme III. Professional commitment and lifelong learning competencies (Chapters 2.13 – 2.18).

When looking across these themes, you may notice common threads, overlaps, and complementary aspects. While each chapter stands by itself and provides an evidence-based, practice-oriented deep dive into the skill covered, you will find adaptable and transversal insights into strategies, methods, and approaches across all chapters that may inform your individual situation. To this end, each chapter, multiple chapters, or all chapters together will contribute to a deepened understanding and informed educational practice. This is a common characteristic of transferable competencies and skills, and mastering these overlaps in practice makes it easier to shape a holistic approach to teaching.

However, several useful insights also sit at the boundaries between these themes. In practice, engineers rarely draw on one competency or skill at a time: they combine and switch between them as situations evolve. Reading across the three themes helps to show how transferable competencies connect and reinforce one another in real engineering work.

The interconnected competency loop. Read together, the chapters show that transferable skills are not add-ons but an interdependent system. For example, feedback literacy (2.11 and 2.12) and self-regulated learning (2.13) support adaptability (2.14) and resilience (2.15) by helping engineers monitor performance, learn from input, and adjust to changing conditions. Looking at these chapters together shows that these processes are central to effective engineering practice, not an optional extra.

From individual attributes to relational processes. Across leadership (2.5) and interpersonal communication (2.10), competency is framed less as an individual trait and more as something enacted with others. In combination, these chapters emphasise the relational nature of engineering: how engineers collaborate, influence, and work within teams and wider networks.

The sociotechnical grounding of professional ethics. Risk management (2.4), information literacy (2.16), combined with ethical awareness as discussed by Bruzzone and Gherardi (2024), position ethics as something delivered through everyday professional practice. For instance, weak interpersonal communication (2.10) is not only a presentation issue: it can limit how well engineers engage stakeholders and integrate critical information, with implications for safety and decision making.

3 Identifying interconnecting themes

Competencies and skills do not exist as isolated entities. Thus, there are always aspects that cut across individual competencies and skills, and, by extension, individual chapters. We have, therefore, identified interconnecting themes that span multiple chapters in Part 2 and address tensions such as prioritising one over the other or the entanglement of autonomy and heteronomy that arise from them. We explicitly invite you to interpret these tensions as productive friction within this debate. They may be catalysts from which constructive approaches to competency and skill development in specific learning situations can emerge. We hope the aspects discussed below provide an additional perspective on the chapters of this part and contextualise them within a broader, overarching narrative, possibly even inspiring a renewed reading of earlier chapters.

3.1 *Progressive development and scaffolding*

As with technical skill, transferable competencies and skills need deliberate development. In your role as an educator, once you create a fruitful learning environment where students can develop these skills, you gradually reduce your support, allowing them to further build competency. By shifting from direct instruction to process-focused scaffolding that alternates between task-specific problem-solving guidance and metacognitive strategic prompts, learners are enabled to assume increasing autonomy (Reiser, 2004). A consistent message across the Part 2 chapters is that you cannot realistically *cover* a complex skill in a single module and expect students to master it. As instructors, we need to think in terms of staged development across an entire programme.

This may mean, for example, starting with basic project skills in the first year, such as simple planning and time management (Chapter 2.2), and then gradually increasing complexity in later years by adding risk management (Chapter 2.4) and meeting facilitation (Chapter 2.3). A similar logic applies to oral and written communication and reporting (Chapters 2.7 and 2.8): early tasks focus on clarity and basic structure, while later tasks ask students to tailor messages to different audiences, negotiate meaning in teams, or justify design decisions.

Self-regulated learning (Chapter 2.13) also benefits from this staged approach (Zimmerman & Kitsantas, 2005). In the early years, the focus is on raising students' awareness of how they study and on fostering self-reflection (Education Endowment Foundation, 2025). As students progress, you increasingly expect them to set their own goals, monitor their learning, and adapt strategies independently (Pintrich, 2004; Zimmerman, 2002). Programme-level thinking is essential here: you design a trajectory rather than a collection of isolated activities (Crawley et al., 2014).

3.2 *Authentic and experiential learning*

The chapters emphasise that transferable competencies and skills become meaningful for students when we embed them in authentic disciplinary contexts and link them to real-world, application-oriented practices and scenarios. Rather than teaching

communication or *project management* in abstract ways, we invite students to apply and practise these skills in realistic engineering tasks and projects.

To achieve this, we may, for example, use interdisciplinary, project-based modules where students work on open-ended engineering problems or create writing tasks (Chapter 2.8) that mirror professional genres such as design reports or technical briefs. Similarly, meeting skills (Chapter 2.3) are more convincing when students encounter them in real or realistic professional situations, such as industry-linked projects, internships, or stakeholder meetings, rather than in purely artificial classroom exercises.

The common thread is to design learning activities that feel relevant to engineering practice and require students to apply particular competencies and skills. Students come to see why the skills matter because they use them to address authentic tasks, develop a sense of self-efficacy, and experience learning as a holistic, integrative process (Johannsen, 2023; Kolb, 2015).

3.3 Reflection and feedback literacy

Although having concrete experiences is important in learning, many chapters make clear that experience on its own is insufficient. Students need structured opportunities to pause and reflect on what they did, how they did it, and what they might do differently next time (Hermsen et al., 2023; Kolb, 2015). In other words, reflection helps them to turn their experiences into learning outcomes (Chapter 2.13).

Across all chapters, authors provide different strategies that help students in cultivating reflective habits that not only support a single competency or skill but also their broader personal and professional growth. As elaborated in Chapter 3.6 on portfolios, it can help your students to keep short reflective journals (Chapters 2.13 and 2.15), write brief commentaries on their team roles, or use frameworks such as Gibbs' or Kolb's cycles to systematically think through critical incidents (Gibbs, 1988; Kolb, 2015; Moon, 2004). Over time, these repeated practices become standard, help students to identify patterns in their behaviour, and take more ownership of their own development.

Alongside reflection sits feedback literacy (Chapters 2.11 and 2.12), understood as the knowledge, skills, and dispositions needed to effectively engage with feedback (Carless & Boud, 2018). Recent work (e.g., Carless & Young, 2024; Coppens et al., 2025) highlights the central role of self-reflection in developing this literacy: students become more able to interpret feedback, evaluate the quality of their own work and that of others, and connect external input to their learning processes when they are prompted to articulate their thinking and monitor their progress. To cultivate these capacities, students need support in recognising the diverse forms feedback can take, managing the emotional dimensions of critique, and translating suggestions into concrete action (Tai et al., 2018). Several chapters show how you can embed this into your teaching practices through structured peer feedback activities, dialogue around criteria, and opportunities to revisit and revise work.

3.4 *Interpersonal relationships and collaboration*

Across the three themes, interpersonal relationships play a central role. Leadership (Chapter 2.5) is presented less as an individual status and more as something that happens in and through a team. Consequently, teamwork (Chapter 2.6) plays an important role and relies on communication (Chapter 2.11), conflict resolution, negotiation, and shared decision making (Driskell et al., 2018; Xyrichis & Ream, 2008).

You will already know from practice that simply putting students into groups does not guarantee that they will develop teamwork skills. The chapters in Part 2 underline this: we need to be explicit about expectations, provide models and language for productive interaction, and give students space to talk and reflect about what did and did not work in their collaboration.

3.5 *Technology, emerging tools, and contextual sensitivity*

Several chapters also touch on the role of technology and emerging tools, including (generative) artificial intelligence, in shaping how we approach competency and skill development. Digital platforms, simulation environments, and AI-supported tools can open new possibilities for practice (Chapter 2.8) and feedback (Chapter 2.12). Yet they also bring new challenges, for example, on critical evaluation, information literacy, and ethical use, as well as a temptation to rely on easy solutions that might backfire and trigger a deskilling and attrition of cognitive abilities of learners and users (Arnold et al., 2023; Hughes, 2021). Developing ethical awareness is critical for educating responsible engineers of tomorrow, and it therefore needs to be given an integrated place within the curriculum. One effective approach is to create opportunities for students to engage with ethics by embedding it in projects, exploring it through teamwork, or using it as a focus for critical reflection during classroom activities (Bruzzzone & Gherardi, 2024).

At the same time, you cannot treat these developments as universal. What counts as authentic and appropriate use of technology will depend on your institutional setting, the engineering disciplines you work with, and the norms of your local context. The chapters collectively encourage you to remain open and critical: use technology where it genuinely supports learning and remain alert to its limitations and risks.

3.6 *Overlaps and cross-pollination*

In Part 2, the chapters show that competencies and skills do not live in separate boxes. No single competency or skill can be isolated and developed independently of its context. Self-regulation (Chapter 2.13), autonomous motivation (Chapter 2.17), and perseverance (Chapter 2.18) connect tightly: when students set their own goals and track progress, they are more likely to stay engaged and push through difficulties. Self-efficacy, thus, is highly relevant for academic achievement (Khine & Nielsen, 2022). Feedback literacy (Chapters 2.11 and 2.12) and communication (Chapter 2.10) reinforce each other: students cannot make good use of feedback if they do not understand how to ask for it, evaluate and discuss it, and translate it into action.

Seeing these overlaps helps to design learning activities with double benefits. A well-planned team project (Chapter 2.6), for instance, can support communication, responsibility, leadership, and self-regulated learning all at once, if those goals are made explicit and students are given time to reflect on them. Having explicit learning goals for these competencies — and for how they come together through project work or complex problem-solving tasks — is essential for students to understand what they are about to learn. Having reflective moments where students can review and evidence their growth is equally important.

3.7 *Intended learning outcomes and assessment*

Finally, if you want to develop transferable competencies and skills, you will need to start from these intended learning outcomes and consider, as we have argued, your distinct context (Biggs & Tang, 2011). The chapters in Part 2 provide ample guidance on how you can go about it in your educational practice. However, you will need to not only build on didactical and pedagogical methodology but also align assessments accordingly. Building on a deepened understanding of the nature of transferable competencies and skills and insights into how to develop them in students, assessment needs to address their performative nature. Part 3 provides you with evidence-based guidance regarding assessment, covering various forms of assessment, from peer to self-assessment (Chapter 3.2 and 3.3 respectively), rubrics (Chapter 3.4), observations (Chapter 3.5), portfolios (Chapter 3.6), and inclusive and ethical assessment (Chapter 3.7).

3.8 *Common themes in Part 2*

Looking across all chapters in Part 2, you can see a common trajectory or shared direction of travel. Focus shifts from students simply knowing about a skill to them being able to use it in practice. That shift carries several transversal structures and tensions that are helpful to make explicit.

All chapters, in different ways, advocate for competency development that goes beyond basic knowledge and understanding, much like how we want our students to excel in their technical expertise. Such competency development also encompasses abilities and motivation that are aimed at (professional) performance and are the object of lively debate, as Chapter 1.2 has shown. It follows that we are not just helping students to recall definitions of teamwork and leadership; we are supporting them to act as competent team members, emerging leaders, or self-directed learners in specific engineering settings.

This application-oriented approach requires you to design learning activities where students are encouraged to use the respective skill in context, collect feedback, reflect, and try again. It also requires you to think carefully about how you describe your learning outcomes. For example, *'students can explain principles of project management'* leads to very different teaching and assessment than *'students plan and coordinate a small engineering project within a team'*.

This approach is commonly referred to as constructive alignment (Biggs & Tang, 2011). If we want students to develop particular competencies and skills, we need to

align learning outcomes, teaching methods, and assessment tasks. As such, alignment takes into account a number of stages and inputs; we first observe the educational goals and how they are formulated, then we look at how we, as educators, develop relevant learning material and engineering learning contexts through which students can learn. These two bring out the intention and the execution but may still not necessarily lead to competency development in engineering practice. To see how these intended and taught elements come together, we need to see the learning outcomes in which student levels of competency and skill development are visible, potentially including those that were not initially intended in the first place (Kovacs et al., 2023). Developing and mapping an overview of how to achieve alignment in the intended, taught, and learnt curriculum, therefore, requires multifaceted reflection on our own curricular intentions, but also on how we construct learning materials and even how we teach transferable competencies and skills, including through our own modelling of professional engineering practice. Part 2 thus leads to Part 3 of the handbook, which focuses on assessment. By reading about and experimenting with the skills in Part 2, you are already laying the groundwork for more coherent assessment practices by clarifying what matters, where your activities are best situated within your programme, and how you might recognise progress in students' engineering work.

A transversal tension may result from the level of standardisation of your approaches. On the one hand, you benefit from shared frameworks and tools. Among these are a common language for self-regulated learning, agreed criteria for communication, or standard templates for project planning. These can support consistency for students and staff. On the other hand, each programme, institution, and student cohort is different. Strategies that work in a small, project-heavy programme may not translate directly to a large, lecture-based curriculum. As always, context matters significantly. The message to take home from Part 2 is to treat frameworks and tools as resources to interpret and adapt, rather than fixed prescriptions.

This entails working in a space where theory informs practice, but where practice remains sensitive to context. We draw on established models, but we also listen to our students, colleagues, and institutional constraints when deciding how to implement them. That also means that you are never alone on this journey: every step you take to improve your educational practice is rewarding for you and for the people around you, whether they are students or colleagues. Often, all it takes is courage and a leap of faith to try something new.

Finally, many chapters highlight ethical and social aspects that cut across individual skills. Risk management (Chapter 2.4), for example, is connected to questions of who carries risk, who benefits, and how decisions affect different groups. Leadership and responsibility (Chapter 2.6) are linked to values, power, and accountability. Lifelong learning and information literacy (Chapters 2.13 and 2.16) are tied to broader debates about inclusion, access, and social justice. You can use these transversal themes as prompts in your own teaching. When students design a solution, you might ask them to think about whose problem they are solving, whose voices are missing, and what

unintended consequences might arise. In this way, we link individual skill development to wider questions about engineering's role in society and can contribute to a holistic education.

4 A toolbox for the transition from reflection to application

Another way to look at Part 2 is to think of these chapters as a toolbox rather than a checklist. It brings together a set of skills, concepts, and teaching approaches that you can draw on and adapt, depending on your aims and constraints. Every chapter provides orientation on a specific competency or skill by offering insights, evidence, helpful recommendations, and further readings to follow up. Consequently, Part 2 is not a call to implement everything everywhere; instead, it offers options and examples to work with.

We believe that this handbook provides a rich resource to enhance educational practices. To ensure maximum benefit, we would like to share a few helpful pointers to be considered when using this toolbox. First, skill development is always shaped by its context. Institutional culture, existing curriculum, and assessment practices will influence what is possible. Second, this is a developmental process, not a single intervention. Competencies grow through repeated, structured practice and opportunities for reflection. Third, instructors play a key role in shaping how students encounter this process, both in their teaching and across the wider programme. There are several practical ways you might use the chapters in Part 2:

Mapping your curriculum. The skill descriptions and implementation ideas can help you see where competencies already appear, where they cluster, and where gaps may be forming. This supports more coherent learning trajectories and can reduce unnecessary pressure on individual modules.

Designing or revising modules. You can adapt examples of project-based learning, reflective tasks, or feedback approaches from the chapters. If a particular approach is relevant to your context, pilot it in one module first and then decide whether to scale it across the programme.

Creating competency profiles. The chapters can help you articulate what graduates of your programme should be able to do. These profiles can be useful in discussions with colleagues, students, and external stakeholders. For more examples in other institutions, see Part 4 of this handbook. Across all of this, iteration matters. Experiment, gather feedback, reflect, and adjust. We hope that, over time, Part 2 becomes not only a toolbox but also a set of shared reference points for ongoing conversations about competencies and skills within your programme.

We would like to emphasise that competency and skill development is a team effort that needs to be based on strategic curriculum development and will be much more successful if it is supported by educational staff at the programme level. However, someone needs to take the initiative. So, start small but think big, because you, as an individual, have agency in this process and may even drive it.

As you move on from this reflection, we would like to share some of our top tips:

Start with one change. Try one new activity or adapt an existing one: a small reflective task, a revised project structure, or a clearer progression within a skill. Piloting something in a single module is often enough to reveal what could scale.

Make skills explicit within what you already teach. Show how competencies and skills connect to disciplinary content and authentic engineering problems, and where they matter. Show where they already appear in your modules, tasks, or curricula.

Revisit learning outcomes. Check whether the learning outcomes genuinely reflect the competencies and skills you value, and whether your teaching and learning activities make progress visible.

Form alliances. Share experience informally, create a forum to exchange practice, and build communities of practice that can support programme-level change and, over time, institutional transformations.

5 In closing

In this reflection chapter, we have first discussed various aspects from an abstract, more structural perspective. In doing so, we intended to illustrate how competency and skill development are context-dependent and that we must consider the specific learning environment within each module in which they take place. Competency-oriented educational outcomes, however, are more effective if their development is embedded in strategic interventions, i.e., if evidence-based, methods-guided competency development starts from intended learning outcomes, extends through curriculum development to programme-level design, and is, in due course, mirrored in institutional transformations.

Secondly, although competencies are individually embodied, a decisive role nonetheless falls to us educators and our concrete practice. Learners develop competencies and skills through experience-based, method-guided activities combined with coherently structured processes of reflection. In this interplay, sustained effort is required. The chapters of Part 2 provide guidance, recommendations and examples to this end. While each chapter provides a stand-alone approach to its competency or skill, they are complementary in nature, as there are significant overlaps. In this chapter, we have sought to summarise a comprehensive understanding of the concept of competency as it is developed in this handbook and to relate it to interconnecting themes and tensions within this part.

Reflecting on Part 2, thirdly, it becomes evident that competency and skill development occurs systematically and strategically rather than additively. To realise its full potential, it should be embedded across individual modules and should interdependently reinforce interventions. Again, this requires individual action and may start with minimal effort and, speaking from our own experience, a bit of courage. Building on that, individual activities may lead to the progressive development that is preferable for achieving the intended outcome. However, as you may want to start at module level, following the constructive alignment approach may prove most fruitful. Here, intended learning outcomes inform teaching and learning practice as well as

suitable assessment activities that address the specific performance dimensions of competencies and skills. Accordingly, Part 3 of this handbook covers assessment and explores various evidence-based methods you can employ.

Finally, in line with principles of progressive competency and skill development, it is essential to consider the respective stages learners transition through and may have reached when taking a particular module. In addition, from a more systemic perspective, it may prove useful to take into account various ways in which learning activities build upon and intertwine with one another. We believe that Part 2 of the handbook has demonstrated in what way individual competencies and skills are a necessary point of departure for teaching transferable competencies and skills. At the same time, we believe that their full potential may only be realised if these initiatives are embedded within overarching strategic decisions. As a coordinated endeavour, they reinforce each other. This systemic perspective, as discussed here, follows naturally from each chapter and, in conclusion, points towards the contributions in the following parts of this handbook. Most importantly, however, it is your everyday practice that these outcomes rely on. Only you can bring them to life for your students. The impact lies in the choices you make in your teaching, and in how you create the conditions for students to learn and apply what they have gained.

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AI statement

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Part 3 Assessing Transferable Competencies and Skills

3.1

Navigating the Complexities of Competency Assessment: An Introduction

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Engineering education increasingly emphasises the development of transferable competencies and skills alongside disciplinary knowledge yet assessing these remains challenging due to their complex, context-dependent, and often intangible nature. This chapter introduces Part 3 by positioning competency assessment as a central but complex aspect of engineering education and offering a critical examination of how underlying assumptions shape what is valued and assessed, often creating blind spots. Drawing on lenses such as constructive alignment, Habermas' knowledge interests, and the four Ps framework, the chapter explores how assessment both verifies learning and signals what *counts*, influencing student priorities and learning behaviours. It addresses key challenges, including the limits of single-point and product-focused assessment, issues of validity when using proxies for competence, and tensions between formative and summative purposes. The importance of inclusive, transparent, and context-sensitive assessment is highlighted alongside practical constraints such as workload and feasibility. Emerging developments, including generative artificial intelligence (AI), further emphasise the need to move towards more process-oriented and authentic approaches. Overall, this chapter provides you with a conceptual foundation for Part 3, preparing the ground for subsequent chapters that present concrete assessment approaches to be selected, combined, and adapted across diverse educational contexts.

1 Introduction to Part 3

Assessing transferable competencies and skills is an essential and integral part of engineering education practice, as it ensures that students have developed the broad set of abilities required for modern professional practice as set out in guiding frameworks (see Chapters 1.3 and 1.4). These frameworks include not only technical knowledge but also communication, teamwork, ethical reasoning, leadership, and problem solving. As curricula become increasingly outcome-based, educators must be able to show that students have achieved these intended learning outcomes for the benefit of the students, accrediting bodies, and their future employers. Assessment is the central mechanism for verifying that graduates meet both institutional expectations and external accreditation standards. This aligns with Biggs' (1996) principle of constructive alignment (as introduced in Part 2), which emphasises the alignment between intended learning outcomes, teaching and learning activities, and assessment. Within this framework, assessment is not merely a tool for verification but a central component in ensuring that students engage in the kinds of learning activities that lead to the development of the desired competencies.

Despite its importance, the assessment of transferable competencies and skills presents significant challenges. Many of these competencies and skills do not have concrete, easily measurable outcomes. While factual knowledge can be tested through recall-based assessments and technical skills can be demonstrated through tangible outputs, competencies such as leadership, collaboration, or ethical judgement are more complex and context-dependent. They develop over long periods of time and often manifest in subtle, qualitative ways (see Chapter 1.2). For example, it is straightforward to describe the characteristics of an effective leader, but far more difficult to measure leadership development in a meaningful way within the typical teaching and assessment timeframes of higher education modules. This complexity ideally requires assessment approaches that are flexible, and capable of capturing growth rather than simply verifying performance at a single point in time. For this reason, assessment of transferable competencies and skills cannot be understood as a purely technical measurement problem but must be approached as a matter of educational design and professional judgement. In formal education, assessment is one of the most powerful drivers of learning (Frederiksen, 1984). What we choose to assess, students will prioritise; what we do not assess, students quickly learn to treat as peripheral (Alderson & Wall, 1993; Baartman et al., 2007). Therefore, we must ask, what informs the choices of what and how to assess?

This opening chapter provides you with a conceptual foundation for Part 3 of the handbook by examining the epistemological foundations, purposes, limitations, and design considerations of assessing transferable competencies and skills. It prepares the ground for the chapters that follow, each of which presents an assessment approach that you can select, combine, and adapt to your educational purposes and context.

2 Epistemology in assessment in engineering education

According to the Theory of Planned Behaviour (Ajzen, 1991; Bosnjak et al., 2020) human behaviour is guided by beliefs: “*beliefs about the likely consequences of the behaviour (behavioural beliefs), beliefs about the normative expectations of others (normative beliefs), and beliefs about the presence of factors that may facilitate or impede performance of the behaviour (control beliefs)*” (Bosnjak et al., 2020, p.353). Normative and control beliefs may lead to prioritising the learning content students expect to be assessed. Assessors’ choices of what and how to assess are likely shaped by the normative expectations of their professional context.

Normative expectations of assessment in engineering education are influenced by the context of education in general and by the ontology and epistemology of the engineering field. Ontology is the philosophical study of being; it deals with how you view the world and the reality, taking your assumptions about the nature of the world and the reality into account (Easterby-Smith et al., 2012). Epistemology is the philosophical study of knowledge and knowing, that concerns the nature and justification of human knowledge (Hofer, 2001; Hofer & Pintrich, 1997). Epistemology is to know what knowledge is, how a person acquires it, and what a person knows (Ghazali, 2021).

Historically, the dominant epistemological tradition in engineering education is positivism, resulting in a dominance of quantitative and positivist work in engineering education research (Beddoes, 2014). Positivists believe that the world can be studied best through objective observations. Reality is believed to be consistent and independent of perception. This reflects engineering in general, where knowledge is expected to be objective, measurable, and transferable.

The ontological position underlying this paradigm is realist. In realism, it is believed that the world is real and science proceeds by examining and observing it. Realism is the belief that there is a single truth, and that facts exist and can be revealed through experiments (Easterby-Smith et al., 2012). A realist will attempt to uncover the truth and will tend to use a positivist epistemology, starting with a hypothesis and proceeding with conducting an experiment that will prove or disprove this hypothesis. Engineering education assessment often takes the form of an exam or an experiment, as these can be objectively measured. Therefore, students often prioritise this form (Ghazali et al., 2021), thus aligning with the epistemological and ontological positions within engineering.

Engineering education not only fits well within a positivistic ideology (Lederman et al., 2023) but also with a dualistic worldview where there are two, often opposing, points of view or answers to a question (Zhu et al., 2019). As noted above, objectivity is key in engineering and therefore many engineering students, and a significant number of educators, approach learning from this dualistic ideology: knowledge is right or wrong, true or false, relevant or not relevant. This might originate in the history of technical universities (Geschwind et al., 2020) and may be reinforced by the labour market, by the professional norms of engineering, and by the need for engineering lecturers to

understand STEM pedagogy (Winberg et al., 2018). In the positivistic worldview, knowledge must be observable; learning must be demonstrated through visible behaviours; assessment must be objective. Anything that cannot be reliably measured risks being judged as peripheral, inferior, or unscientific. Our institutional systems, such as accreditation, quality assurance, and performance indicators, reinforce this stance by rewarding the quantifiable and often leaving the rest unacknowledged. In doing so, forms of learning of knowledge and competencies that are subjective, tacit, relational, intuitive, indigenous, ecological, embodied, or learning that is different in other ways can be sidelined. These are just as essential to becoming a responsible engineer and a whole human being, but they do not sit comfortably within our dominant engineering beliefs. As a result, they often fall out of sight. These epistemological assumptions help to explain why transferable competencies and skills are often marginalised in assessment. The following section therefore examines why, despite these challenges, it remains essential to assess them explicitly.

3 Why do we need to assess transferable competencies and skills?

3.1 Accreditation, accountability, and employability

The shift toward outcome-based education further reinforces the need for explicit assessment (Biggs, 1996). Accrediting bodies increasingly require evidence that students have developed the competencies necessary for professional practice at a required standard (Almuhaideb & Saeed, 2020; ENAEE, 2008). This cannot be demonstrated through assumptions or informal impressions; it requires systematic assessment practices that document and verify attainment. In this way, assessment serves not only pedagogical purposes but also institutional accountability. It ensures that programmes of study can substantiate their claims about graduate capabilities and maintain alignment with professional standards.

At the same time, employability and the rise of institutions committing to related graduate attributes (Spronken-Smith et al., 2013; Wong et al., 2021) further strengthen this need, as graduates are expected to demonstrate not only technical expertise but also transferable competencies and skills that enable them to function effectively in complex, inter- and transdisciplinary, and evolving professional contexts.

3.2 Assessment as a driver of development

Alongside this verification of achievement, assessment also plays several important roles within the learning process itself. It supports learning by giving students feedback on their progress and highlights areas where further development is needed. It allows students to benchmark their own achievements. It also makes the curriculum visible: across our modern education systems, what is assessed signals to students what is valued by you as an educator. When competencies are not assessed, they risk being perceived as optional. Students naturally focus on what is graded, and if transferable competencies and skills are not part of the broader assessment framework, they may receive less attention than technical content (Alderson & Wall, 1993; Baartman et al., 2007). This undermines the overarching goals of modern engineering education, which increasingly emphasise the importance of adaptability,

interdisciplinary collaboration, and responsible decision making. By integrating transferable competencies and skills into assessment, you as an educator signal their importance and ensure that they are embedded within students' learning strategies.

At the same time, assessment provides the structure that meaningful competency development requires. Students cannot improve in areas such as teamwork or communication unless they understand what these competencies involve, what is expected of them, and how their performance will be evaluated. Clear learning objectives and explicit assessment criteria give students direction, while feedback helps them identify strengths and weaknesses and pathways to improvement. Assessment transforms broad, abstract competencies into concrete learning outcomes that students can work toward. Without this structure, competency development can become inconsistent and dependent on chance rather than on intentional educational design.

Assessment therefore also plays a developmental role that extends beyond measurement (Biggs, 1996). Through formative feedback, reflective activities, and opportunities for iterative improvement, assessment helps students internalise the habits and mindsets associated with professional competence. It makes learning visible, both to you as an educator and to students themselves, enabling students to recognise their progress and take ownership of their development.

This is particularly important in engineering, where graduates must be prepared to navigate complex, rapidly changing environments (SEFI, 2025). Transferable competencies and skills enable engineers to develop throughout their careers, work effectively in diverse teams, communicate with stakeholders, and make informed ethical decisions. Assessment supports the cultivation of these abilities by encouraging students to reflect on their performance, recognise areas for growth, and take deliberate steps toward improvement and lifelong learning.

By assessing transferable competencies and skills, you create a learning environment in which expectations are clear, feedback is meaningful, and students understand the relevance of their development beyond individual modules. This combination of clarity, accountability, and developmental support makes competency assessment indispensable for preparing future-ready engineers who can thrive in complex professional contexts.

4 Blind spots in engineering assessment

Building on the epistemological assumptions outlined above, and the challenges of holistically and meaningfully assessing transferable competencies and skills, the focus on objective assessment at the expense of other types of learning and development leaves important gaps within engineering education assessment.

Habermas' theory of knowledge interests (1971, 1973) offers a helpful lens to indicate what is being excluded. The doctrine of interest is a theory in which Habermas suggests that humans construct knowledge according to three fundamental interests. In these terms, interest means a fundamental orientation of human thinking by which

humans develop means and methods for promoting life. These interests are technical (control and prediction), practical (understanding through interaction) and emancipatory (reflection, autonomy, and transformation). Engineering education overwhelmingly prioritises the technical interest. Denton (2011, p. 847) explains this further: “*The technical interest represents the fundamental human desire to control the environment through principles of positivism (Habermas, 1971). Because of its positivistic nature, the technical interest requires careful definitions, set criteria, and verification. Moreover, the overall purpose of these methods is to produce predictable outcomes. An accompanying dynamic associated with predicting outcomes is the careful monitoring of input and output mechanisms*”.

Denton and Habermas do not imply that there is something wrong with the technical interest, but that an overemphasis on the technical interest is problematic in educational practice (Ellis 2005).

Specifically for engineering education, Dias de Figueiredo (2008, p. 94) echoes Ellis (2005) and states what it means to be an engineer and gain engineering knowledge: the engineer should be “*a sociologist, scientist, designer and doer*”. This means that engineers not only need technical skills and knowledge, but also transferable and social skills such as social interaction, ethical reasoning, intuition, and self-reflection. When these competencies and skills appear in curricula, we need to be mindful of the approach, as the dominance of positivistic epistemology creates two major blind spots.

Firstly, we mistake a subset of knowledge for the whole. Technical, analytical, and procedural knowledge becomes the centre of the curriculum, not because it is the entirety of what engineers need, but because it is easiest to define, teach, and assess and it is what educators are most comfortable with and can account for easily.

Secondly, when we do engage with subjects and forms of learning that lie outside this subset, such as the development of competencies and skills related to collaboration, reflection, integrity, empathy, or professional identity, we tend to force them into our existing frame and view in order to, as discussed in Section 3.2, ensure that their value is made clear. We attempt to make them measurable; we produce rubrics to evaluate them; we make systems that define and organise them; and we assign grades. In doing so, we risk distorting the very thing we intend to cultivate.

We can illustrate the second point by looking closer at the role of constructive alignment. Constructive alignment (Biggs, 1996) is widely celebrated as a gold standard (Claassen, 2005) in the assessment of engineering education. In curriculum design principles, it enhances coherence: learning outcomes, teaching activities, and assessments should all point in the same direction. However, constructive alignment, when uniformly and uncritically implemented in curricula with a positivist epistemology, can become a constraint.

It pressures us to write precise, measurable outcomes for learning processes that cannot, and arguably should not, be pinned down. If we declare that learners must ‘*demonstrate empathy*’ or ‘*show reflective depth*’, we are compelled to create assessments for these outcomes. Furthermore, because our system demands

objectivity, we create metrics or rubrics for what is fundamentally unmeasurable (Veen et al., 2020). The result is a curriculum designed around what can be measured, not what is valuable.

Our call to action is simple, though not necessarily easy: pause, notice, and reflect. We need to make our blind spots visible. We need an honest dialogue about how our epistemological assumptions shape our practice, about how our assessment regimes reinforce those assumptions, and about what and whom we are excluding in the process. This is not a call to abandon rigour or objectivity. It is a call to recognise that they are not the whole story.

5 What counts as evidence? Proxies for competency

These challenges raise a fundamental question: what counts as valid evidence of competence. Fawns et al. (2026) dive deeper in constructive alignment and the validity of assessment. They argue that while constructive alignment is often used in higher education to support assessment validity, in practice test validity is often verified through peer review or mapping exercises, resulting in little more than face validity (whether a task appears to measure what it is intended to measure) or content validity (whether a task adequately covers the intended content). Fawns et al. (2026) present the four Ps framework as a useful tool for educators who are not assessment specialists to move beyond surface level checks. The four Ps stand for 'four proxies'; a proxy is a form of evidence that stands in for broader, less visible capabilities.

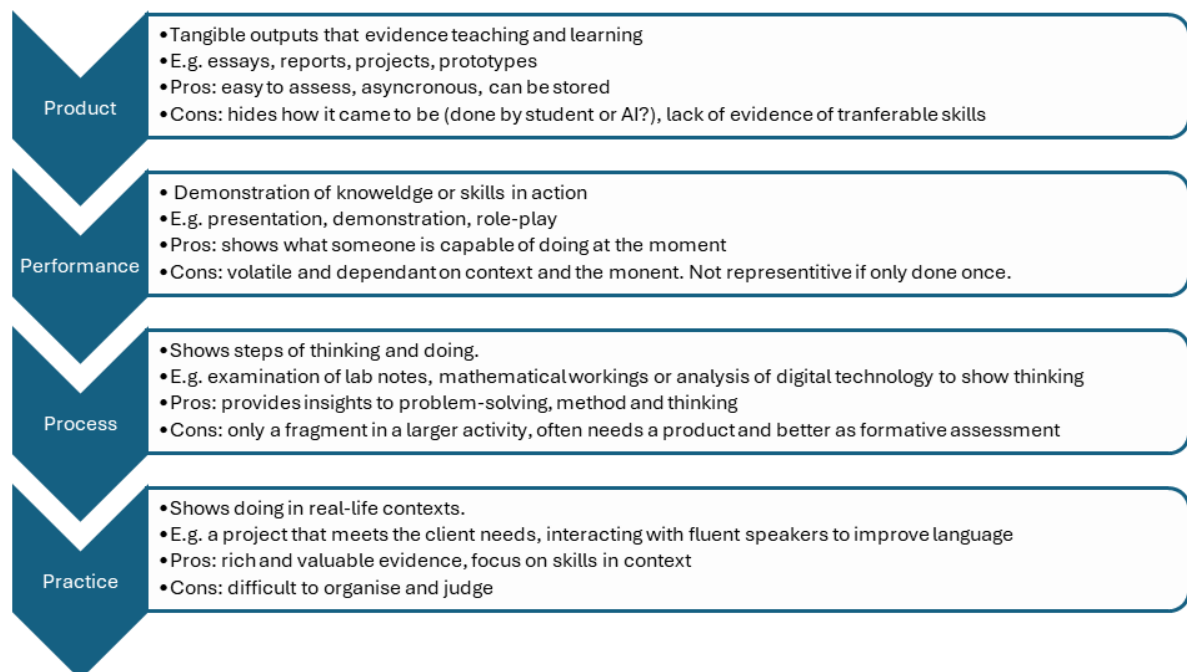


*Figure 3.1.1: Steps within the four Ps framework
(Own Work based on Fawns et al., 2026)*

The four Ps framework encourages you to critically consider whether the evidence generated by assessment tasks genuinely proves graduates' capabilities or whether

assessments should be modified to strengthen the connection between evidence interpretation and the stated learning outcomes.

Fig. 3.1.1 shows the proxies that Fawns et al. (2026) use to describe the assessment of learning. Each of the proxies explains what they are, lists examples of each as well as some general pros and cons. However, when a proxy is used, it needs to be appropriate for the assessment. The risk arises of misalignment with the original assessment intentions, resulting in an assessment that does not truly assess the intended learning outcomes. Fawns et al. (2026) go on to describe five ways of misalignment with what you want to assess (Fig. 3.1.2).

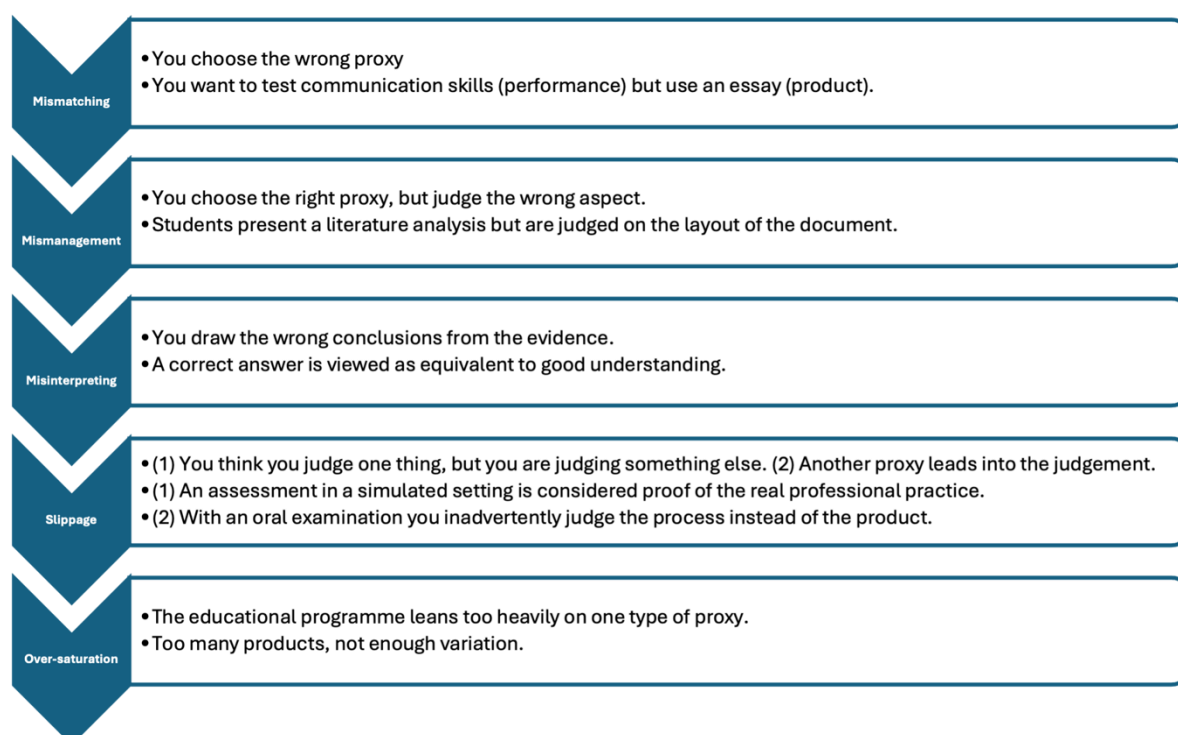


*Figure 3.1.2: Summary of misalignment of proxies
(Own Work based on Fawns et al., 2026)*

To try to solve the misalignment issues shown in Fig. 3.1.2, Fawns et al. (2026) discuss synthesising assessment through aggregation (for example adding or averaging grades), triangulation (comparing different proxies for coherence), and holistic assessment. The four Ps framework offers a useful way for us to evaluate our assessment practices and discuss how assessment can generate credible inferences about what students know, understand, and can do.

6 Context, development, and the limits of assessment

6.1 Context

When deciding on assessment, several factors are involved, including context. Context plays an important role, as it involves the participants of the assessment (their needs, expectations, backgrounds, barriers), the educational situation (education level,

location etc.) and the culture (of the students, university, and place of study). Each of these areas within context is key and must be considered, and adjustments to assessments need to be made in order to make them relevant for all stakeholders.

As Boud (2000) discusses, assessment carries implicit power and indicates implicit values. Therefore, it must be designed with transparency, fairness, and inclusivity at its core. Transparent assessment ensures that students clearly understand expectations, criteria, and the rationale behind evaluating particular competencies. Fairness requires that assessments provide equitable opportunities for all students to demonstrate their abilities, without privileging those who are already familiar with certain cultural or educational norms. Inclusive practice is especially critical in engineering education, where traditional curricula and assessment practices can unintentionally disadvantage students from diverse linguistic, cultural, or educational backgrounds or those with undisclosed disabilities. Competency-based tasks that rely heavily on implicitly accepted communication styles, culturally specific teamwork norms, or prior exposure to professional or certain social environments may obscure rather than reveal students' true capabilities (Tai et al, 2021). Inclusive assessment is therefore both an ethical responsibility and an educational necessity. Poorly designed assessments may unintentionally privilege students who are already familiar with dominant cultural or educational norms. It is therefore important to consider this when designing assessment. See Chapter 3.7 on inclusive assessment for further details.

Inclusive approaches such as offering clear instructions, alternative formats, and culturally sensitive contexts promote equity and accessibility, reduce anxiety, and foster a sense of belonging. In this way, you support assessments that measure intended learning outcomes rather than unrelated variables such as prior privilege or access to resources. Ultimately, designing assessments with inclusivity in mind not only supports individual success but also prepares graduates for diverse professional environments while maintaining the true validity of assessment. Only when all students can meaningfully engage with an assessment can it accurately reflect their capabilities. Therefore, Holmes (2004) suggests an open-minded approach with greater cultural understanding.

In terms of competencies and skills development, culture can influence the importance of some skills over others, as well as beliefs regarding those skills. For example, Courtney and Du (2015) developed a framework for Chinese learners where academic skills such as plagiarism and academic misconduct are addressed first under the competency '*being a responsible learner*', while critical thinking is addressed later. This shows that beliefs about learners influence the order in which competencies and skills are presented.

Thus, assessment of transferable competencies and skills should be designed for the specific needs of students, in addition to programmes or disciplines, because then individual differences can be better supported, leading to greater student success and achievement of learning outcomes.

6.2 Development

Assessing transferable competencies and skills presents a range of persistent and interconnected challenges for educators and institutions. Unlike discrete knowledge acquisition, competency development requires practice, is often non-linear, and most often unfolds over long periods of time, making it difficult to pinpoint when a competency has genuinely been acquired. A student's acquisition cannot be easily linked to a specific learning activity nor a single point in time. As a result, assessment systems must be flexible enough to capture development that is gradual, uneven, and deeply contextual.

Assessment in higher education is most commonly criterion- and standards-based and is rarely a direct measurement of learning gain or an individual's personalised improvement. However, for some students, the learning gain from the beginning of a programme to the point of assessment may be far smaller than for others, often depending on prior experiences and social capital. Alongside this, the development of professional competencies is often incremental or qualitative in nature. Competencies such as collaboration, critical thinking, or ethical reasoning rarely show dramatic, easily measurable leaps; instead, they evolve through subtle shifts in behaviour, mindset, and performance. Traditional assessment tools often struggle to detect these small changes, and even well-designed rubrics can fail to reflect the richness of students' developmental journeys. This raises questions about the validity and sensitivity of the instruments used to measure progress and underscores the potential value of incorporating more process-oriented and reflective forms of evidence.

6.3 Limits of assessment

Professional competencies are, by definition, transferable across contexts, so evaluating them in isolation risks fragmenting what should be a holistic picture of student development. Programmatic assessment offers a more integrated perspective, but it requires coordination across degree programmes, shared criteria, and a common understanding of expected levels of achievement.

Wider education systems also need to support this approach, which can conflict with institutional regulations around progression and assessment. As a result, the conditions required for programmatic assessment are not always easy to achieve.

A further complication lies in balancing formative and summative assessment approaches. Formative assessment is essential for supporting growth, offering feedback that guides ongoing development, while summative assessment is often required for accountability, certification, and progression decisions. Relying exclusively on one or the other creates distortions: a purely formative system may lack robustness for credit-bearing evaluation, while a purely summative system risks reducing complex competencies to simplistic scores. Therefore, many educators aim for a blended approach but integrating the two in a coherent and meaningful way remains a significant design challenge.

Finally, to ensure educator and student buy-in, workload considerations cannot be ignored. Effective competency development and assessment of this development

demands time: time for students to reflect, time for educators to observe, and time for meaningful individualised and dialogic feedback to be given and understood. The organisation and workload mean the assessment can become centred around process rather than learning. Thus, without careful design, the process of assessing transferable competencies and skills can become overwhelming for both groups, overshadowing the centring of student development. Ensuring that assessment remains manageable while still capturing the complexity of competency development is therefore a central challenge for any educator seeking to implement such an approach. Balancing feasibility with pedagogical richness is thus a key consideration in assessment design.

7 From module-based judgements to programme-level perspectives

A key challenge in assessing transferable competencies and skills lies in the tension between single assessment moments and the longitudinal nature of competence development. This tension reflects a broader shift from modular, isolated judgements towards more holistic, programme-level perspectives on student learning.

According to McCafferty et al. (2025), a spectrum of programme level assessments exists from basic reflection mapping and matrices, followed by integrated assessment, and finishing with the most difficult, programmatic assessment.

- *Stage 1.* Basic reflection mapping and matrices aims to review current practice and increase diversity of assessments.
- *Stage 2.* Integrated assessment aims to design assessment that covers multiple modules or across semesters or years, therefore reducing the number of assessments.
- *Stage 3.* Programmatic assessment involves continuous multiple low-stakes assessments that take place throughout the entire degree.

All stages aim to view assessment from a holistic whole programme view rather than from an individual module perspective. This shows students the connections between modules and learning outcomes.

Programmatic assessment was introduced by van der Vleuten and Schuwirth (2005; van der Vleuten et al., 2012) in medical education and is based on the principle that assessment is a continuous process throughout a programme, as opposed to series of disconnected tests, using multiple low-stakes assessments recorded by portfolio (McCafferty et al., 2025). Programmatic assessment treats each assessment as one piece of evidence within a broader system, combining multiple data points, feedback, and learner reflections over time to support both learning and high-stakes decisions about progression. It does not rely on isolated tests and pass/fail judgements, but uses diverse assessment methods, triangulated evidence, and holistic decision making to provide a more comprehensive, learner-centred evaluation of competence (Heeneman et al., 2021). In this way, students are encouraged to become more self-reliant learners. Educators become coaches and encourage students to record evidence of their learning, which is used to determine a pass or failure. In this way,

assessment shifts from isolated judgements towards a continuous, evidence-informed process of learning and development.

Nevertheless, programmatic assessment requires considerable work from educators in the beginning, as well as iterative development through evaluation (Ryan & Judd, 2022). Compared with traditional assessment, it requires more time investment in feedback provision, learner coaching, and the interpretation of multiple assessment data points to support robust progression decisions (van der Vleuten et al., 2012, 2015).

Additionally, the educational setting must be suitable for it: competency-based educational programmes can align with the use of programmatic assessment, whereas settings where knowledge transfer is the main objective might not. It also requires professional development of educators, as it considerably changes assessment, especially when educators are used to many formative assessment points. This represents a cultural as well as structural shift for an institution .

Additionally, using multiple low-stakes assessments is challenging alongside the call for reducing the number of summative assessments (Elkington, 2020). Therefore, using programme-level integrated assessment may be beneficial in reducing overassessment, as it requires students to “*synthesise and apply their learning across multiple modules*” (Walker, 2025, p. 5). This enables students to develop both knowledge and transferable skills, giving the opportunity to increase the teaching of these skills in a more in-depth manner.

Creating integrated assessment can be done at whole programme or degree level, or part-programme, i.e., by year or stage (Walker, 2025), and this can be context-dependent. However, key components of developing integrated assessment include having clear learning outcomes and assessment activities, all of which take time and collaboration to set up. This again highlights the importance of constructive alignment at the programme level.

8 Future-focused assessment: generative AI and emerging challenges

Emerging developments such as generative AI further challenge traditional product-focused assessment. AI is evolving so rapidly that we realise that anything we write in this chapter and handbook today may be outdated tomorrow. Nevertheless, the topic is too important and wide-reaching not to address when discussing learning and assessment.

With the rise in AI, design of authentic and robust assessment has become more difficult to achieve. Within engineering education, broadly speaking, there are two routes being taken: deal with AI or try to restrict its use. Restriction is unlikely to be a solution, as AI is embedded in so much of the technology we and our students use. Hence, it is important that students not only know how to use AI, but also how to critically evaluate it, understanding its limitations and the ethical implications of its use. When assessments are created, AI use has to be factored in. Myers (2025) states

that we should not ask ourselves how to prevent AI use, or ask ourselves how to deal with AI use, but rather that we should ask ourselves what type of learning we want to protect and how we can design education to foster that kind of learning. Myers suggests activating didactics where the learning process itself is central, not the content. He describes six strategies that make AI use less relevant, as these strategies focus on learning process instead of end products: making assignments more personal and more reflective, showcasing the learning process in a portfolio, collaboration in class, reintroducing slower learning methods like concept mapping, teach with AI by providing students opportunities to analyse it, and talk about why this is important and thus (re)appreciating human elements.

Similarly, Mastrogiacomì (2023, p. 176) discusses how an evidence-based portfolio was used as a reaction to the Italian national AI ban in educational institutions. The author found that to capture creative and iterative teaching in a design module, a personal portfolio containing "*strategic thinking, peer interactions, ability to ask questions and active participation*" was more "*future proof*" than traditional exams, where large language models could be used to provide answers.

Chapter 3.6 discusses the use of portfolios and gives examples of four types. Whilst the example above would constitute a *showcase portfolio*, the most common use of portfolio in higher education is developmental. This enables students to reflect and act on the development of their transferable skills. By personalising a portfolio specifically for each student and their experiences through their university programme, as long as students are provided scaffolding and support, this kind of portfolio could be truly personal, as well as difficult to generate using AI, especially for assessors who are familiar with the module.

Key skills that should be developed when using AI tools are critical thinking, problem solving, and reflection. These skills can be integrated into assessments that use AI. An example of this is an '*egg drop*' challenge where AI was used to virtually assess the design of the students' parachutes, giving them potential shortcomings which enabled them to reflect and improve on their designs (Changzhou Institute of Technology Hertfordshire College, 2025). AI additionally aided the organisation and summaries of the data, enabling students to complete their logbooks. The use of AI in this assessment task saved time and physical resources, freeing students to focus on critical thinking and analysis of the feedback that AI produced, thus aiding in the development of the students' feedback literacy.

The most contentious topic related to AI and assessment is academic integrity and policy. Whilst universities scramble to develop policies and decide on the use of AI, students are already integrating AI tools in their learning. This creates a disconnect between institutional governance and actual student behaviour.

As AI for education is not going to go away, we need to learn to use it well and teach learners the critical thinking and analytical skills required to use AI responsibly. This positions AI not only as a challenge but also as an opportunity to redesign assessment in ways that better align with the development of transferable competencies.

9 Key takeaways and how to use Part 3

Assessing transferable competencies and skills in engineering education is far from a technical exercise; it is a reflection of what we believe knowledge is, how learning develops, and what kind of engineers we hope to shape. This chapter has shown that assessment is inseparable from individuals' preconceptions, culture, ethics, and educational purpose. When we privilege what is easily measurable, we risk narrowing the curriculum and students' understanding to technical content alone, overlooking the relational, reflective, ethical, and context-dependent dimensions of engineering practice. Yet these dimensions are precisely what enable engineers to navigate uncertainty, collaborate across boundaries, and act responsibly in a rapidly changing world. They are the definition of a human engineer.

Assessment is not a neutral act. The competencies that educators choose to evaluate signal what an institution values, shaping how students allocate their efforts and understand their identities as engineers. Alongside this, transferable competencies and skills develop slowly, unevenly, and across contexts. They cannot be captured well through isolated, single points in time or through reductive metrics that distort the very qualities they aim to measure. Instead, assessment must be designed to make learning and what is truly valued visible, support student development and growth, and recognise the nuance and complexity of becoming a professional engineer. This requires moving beyond product-focused approaches towards more developmental, longitudinal, and programme-level perspectives that align with the non-linear nature of learning.

This underscores why the assessment of transferable competencies and skills matters so deeply. It ensures alignment with accreditation and accountability requirements, but more importantly, it supports the development of engineers who can think critically, act ethically, collaborate effectively, and continue learning throughout their careers. Competency assessment is therefore not an optional add on to the curriculum; it is a cornerstone of future focused engineering education.

The chapters that follow offer practical pathways for putting these principles into action. Each assessment approach foregrounds different types of evidence and serves different educational purposes. You are invited to use these chapters reflectively rather than prescriptively: selecting, combining, and adapting methods to suit your own context and goals.

Peer assessment (Chapter 3.2) highlights how students can learn from and evaluate one another's contributions, making teamwork and communication visible. Self-assessment (Chapter 3.3) supports metacognition, reflection, and ownership of learning. Rubrics (Chapter 3.4) help articulate expectations and guide feedback. Observation (Chapter 3.5) captures behaviours that cannot be demonstrated through written products alone, while portfolios (Chapter 3.6) enable the documentation of development over time. As discussed in this chapter, combining these approaches at the programme level can provide a more holistic and coherent view of competence development.

Together, these approaches form a rich toolkit for designing assessment that is rigorous, inclusive, developmental, and future ready. As you continue through this part, you are encouraged to explore how the different methods connect and how they might be combined to create meaningful assessment ecosystems.

Finally, this part also lays the groundwork for Part 5, where evaluation becomes central. The choices made in assessment design directly shape how educational practices can later be evaluated for quality, effectiveness, and impact.

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AI statement

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3.2

Peer Assessment

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Peer assessment (PA) is a well-established and widely used practice in higher and engineering education, aligned with the sector's shift towards active, skills-based learning. It supports students in developing and demonstrating a broad range of transferable competencies, including those highlighted in the second theme of this handbook, namely communication and interpersonal skills; in particular teamwork, interpersonal communication and feedback, as well as general communication. Engaging in PA requires students to review, judge, and evaluate the work of their peers, thereby fostering higher-order cognitive skills and deeper conceptual understanding. This chapter introduces three modalities of peer assessment. First, traditional peer assessment focuses on evaluating the quality of product or output. Second, 360-degree peer assessment extends this by evaluating both the product and the quality of the feedback provided. Third, the individual peer assessment of contributions (IPAC) methodology focuses on assessing individual contributions, teamwork behaviours, and professional competences within group work. The chapter outlines the benefits, challenges and best practices associated with each modality of peer assessment and offers guidance for effective implementation. It is intended to support new and established practitioners seeking to implement effective peer assessment and enhance students' engagement, accountability, and competence development.

1 Introduction

Different forms of educational activities in which students review and judge each other's work and/or provide feedback to each other may be referred to as peer assessment (PA) (Adachi et al., 2018; Fleckney et al., 2025; Topping, 1998).

In engineering education, PA, as an active education approach, can enrich the learning outcomes associated with a technical subject-specific module element to also include transferable competencies (e.g., communication skills, giving and receiving feedback). Even with respect to the technical learning outcomes, PA aims to engage students at a higher level of cognitive complexity to include evaluation and analysis as students critically evaluate their peers' work (Krathwohl, 2002). PA, with its usual elements involving feedback and scores (Fleckney et al., 2025), can promote reflective responsible practice (Topping, 1998), foster critical thinking, and facilitate a better understanding of the assessment criteria (Iglesias Pérez et al., 2022). In addition, the ability to critically evaluate others' work and to take on the role traditionally held by instructors can build the students' confidence for independent learning, an increasingly important attribute in a rapidly evolving job market with changing skills requirements. As such, the PA approach is also increasingly used in industry as part of the performance measurement of their workforce (Bracken et al., 2016), e.g., at HSBC, PepsiCo, and Exxon. Therefore, PA addresses several competencies that are featured in this Handbook.

In this chapter we introduce you to three common modalities of PA: traditional PA, which focuses on the evaluation of a product with respect to its quality; 360-degree PA, which expands the traditional PA to also include the evaluation of the feedback provided by students to their peers to also incentivise giving quality feedback; and the individual peer assessment of contributions (IPAC) methodology, which centres on PA of the individual contribution to group work, targeting teamwork behaviours and individual accountability within collaborative tasks. Together, these modalities represent complementary perspectives on PA, addressing product, feedback literacy, and participation. For each type, we discuss the benefits and challenges, and how they can support the development and assessment of technical knowledge and professional competences such as communication and giving and receiving feedback. We provide two examples and conclude the chapter with some practical advice. The chapter also briefly considers the future of PA in the context of emerging artificial intelligence (AI) tools and their implications for design and implementation.

2 The traditional peer assessment method (PA of a product)

Traditionally, PA is deployed in the context of marking and/or providing feedback on a student product, something tangible. This product can be anything ranging from an answer to a question, to a presentation or a report. For these products there are two main attributes which practitioners may ask students to evaluate:

- *The technical context and content of the product within the subject of study.* Students might be asked to look at the veracity of the information and outcome

presented within the field of study, as well as the correctness of the methods and processes involved.

- *The attributes of effective communication.* This includes communicating at an appropriate level for the target audience, the coherence of arguments, a clear structure, and the effective presentation of elements such as figures to convey the intended message.

When evaluating the subject-specific technical aspects of the product, students may lack sufficient knowledge to provide a reliable and consistent judgement. By contrast, they are well placed to assess the quality of communication as they perceive it. It is therefore reasonable to expect students to evaluate and communicate meaning at their own level, unless the product builds on extensive prior work by the student, requiring more advanced understanding. Therefore, in most cases, peer understanding of the communication of the product provides a useful indicator of its effectiveness.

PA requires the use of marksheets, rubrics, exchange of scores, and feedback. There are specific tools designed to facilitate the implementation of PA, including allocation of work to peers and/or moderation by the practitioner, e.g., Turnitin, PeerMark, and Moodle Workshop activity.

2.1 General motivation and benefits of PA

PA literature indicates that, in the higher education setting, its use may lead to better or equal academic performance when compared to instructor assessment alone (Double et al., 2020, Li et al., 2020). There are multiple benefits that would motivate the use of PA in education.

Higher cognitive engagement and learning of technical knowledge

PA promotes metacognitive reflection and evaluative judgement, particularly when feedback and justification are required (Ortega-Ruipérez et al., 2024), which applies to both technical and communication domains. In providing feedback and justification, students need to analyse, evaluate, and sometimes even create solutions, promoting higher levels of cognitive engagement as per Bloom's taxonomy (Krathwohl, 2002). In other words, in reviewing their peers' work, students must interpret technical decisions and appraise their validity in order to be able to propose improvements, all of which include the characteristics of complex cognitive engagement that effective engineering education seeks to cultivate.

Development of transferable competencies: communication competencies

PA supports the development of communication competencies because students must evaluate the clarity, structure, and communication effectiveness of their peers' outputs, including written reports, presentations, and other deliverables. This also requires students to produce constructive, precise, and professionally appropriate feedback, fostering communication approaches akin to those expected in engineering practice. Adrill's (2025) research on dialogic peer feedback shows that students value

peer assessment as a means of improving their communication awareness, reflective thinking, and feedback literacy.

Development of transferable competencies: growing confidence with critical analysis

Engaging in PA builds students' confidence in critical analysis, as they learn to make judgements based on evidence and criteria. In addition to further enriching learning outcomes with critical thinking and independent judgement, PA can positively impact learner motivation and engagement by expanding perspectives (Adriani, 2025), while reviewer training within PA can further improve learner motivation (Yigitler, 2026). This positions PA as an authentic preparatory practice for evaluative responsibilities encountered in engineering workplaces and research environments.

Facilitation of prompt feedback in large classes using PA

Timely, frequent, and task-focused feedback is fundamental to effective learning (Gibbs et al., 2004). However, large class sizes make it difficult for educators to deliver such feedback unaided. PA addresses this challenge by distributing the feedback workload across students, allowing rapid turnaround that satisfies the requirement that feedback must reach learners while still actionable. Technology-supported PA platforms, including Moodle's peer review tools, FeedbackFruits, or Turnitin can be used to manage the logistics of PA to ensure feedback can be delivered in a timely manner.

2.2 Challenges and mitigations

PA does not come without its challenges, chiefly: (1) concerns around the fairness and validity of the peer marks and feedback; (2) students' lack of engagement with the PA process because of lack of motivation or understanding; and (3) logistical challenges in assigning, collecting, and moderating PA in larger cohorts.

Fairness and validity of PA and student engagement

All students, assessors and assessees, may have concerns regarding the fairness of PA, questioning and challenging their own ability and the ability of their peers in providing an accurate assessment of their work based on their limited experience and technical knowledge about the topic of the assignment. Traditional PA may also suffer from poor engagement with the assessment by the peer assessors if they are not held accountable for the accuracy and validity of their evaluation, further compromising the integrity of the assessment. These issues can affect the quality of feedback and the reliability of summative marks. In fact, there are studies that suggest that formative implementation of peer feedback is more effective (Fleckney et al., 2025), perhaps because it removes the higher stakes of the summative element. However, this may avoid rather than address the underlying issue, while reducing opportunities for students to develop evaluative judgement against standards.

A typical approach to address the students' concerns over fairness in PA is by including multiple peer assessors in each assessment, which agrees with best practices in assessment in general. Although this provides some resilience in peer marking with

respect to fairness, a degree of tutor moderation or assessment of the feedback may still be needed.

Furthermore, evaluating students' reviews of their peers' work and holding them accountable can partially address the engagement issue. This in turn can improve the validity and consistency of PA. This advanced PA method is presented in section 3 of this chapter.

Practical implementation issues

Bespoke PA platforms may facilitate the assignment, collection, and moderation of PA that otherwise places a significant workload for instructors. AI may provide a unique opportunity for assessing feedback and moderating tasks efficiently, but further research is needed into its responsible implementation.

Practitioners should be aware of other practical challenges that can arise when implementing PA in real teaching contexts. For example, PA activities often rely on all students submitting their work on time so that reviews can be allocated and completed within the planned schedule. Late submissions can disrupt the allocation of reviewers and may result in some students receiving fewer reviews than intended.

One way to manage these situations is to design PA activities with some flexibility, for example by assigning multiple reviewers to each submission or by allowing tutors to step in as reviewers when necessary. Clear communication about deadlines and expectations is also important to minimise disruption.

Building feedback literacy

Providing a clear briefing to set the context and motivation for PA may facilitate a more uniform uptake. To further improve the outcome, PA may be deployed in iterations for a given activity and/or comprehensively across a module, as students will need sufficient and structured exposure to the process to develop the associated feedback literacy (Fleckney et al., 2025). Furthermore, by appropriately managing the assessment procedure through the provision of the required standards, introducing scaffolding, and the inclusion of a moderation step, the quality of the outcome in PA (peer feedback and summative score) may be improved (Adachi et al., 2018). For more information on teaching feedback literacy, see Chapter 2.12.

2.3 Design factors

PA is quite flexible and adaptable to different contexts and practitioners' general preferences or motivations, e.g. how the peer assessment is used to grade students. There are various design factors identified by Alqassab et al. (2023) that include the assessment type (i.e., formative and summative), output of PA (e.g., written feedback and mark), group or individual assessment, privacy considerations, mode of delivery (e.g., online or in person), pairing strategies between assessors and assessees, number of iterations, and the scope of involvement of the students. The evidence for some of these design choices in terms of their impact on academic performance is mixed and may depend on the context, but a major design decision is undoubtedly

the choice between formative and summative deployment of PA. Some of the design factors that practitioners need to decide are discussed below in more detail.

Output: qualitative versus quantitative

PA may involve scoring (quantitative) and/or written comments (qualitative). Qualitative feedback can provide detailed guidance to help students to improve their work, while a quantitative score can help instruct the evaluation process and make it easier to incorporate PA into grading systems.

In general, engineers prefer to work with numbers and may gravitate towards quantitative scoring — this is of benefit to the educator, as it gives a clear scale of how the student is performing. However, qualitative feedback is usually much richer and useful for students to learn from, both when giving and receiving feedback.

Assessment type: formative vs summative

Formative PA focuses on supporting learning. Students provide feedback that can be used to improve their peers' work before a final submission. This encourages reflection and helps students to develop evaluative judgement. Summative PA contributes directly to grading, e.g., when peer marks are used to grade the product of the students. As such, summative PA can raise concerns about fairness, quality, or reliability of the marks if the process is not carefully designed.

Summative PA may be the desired option among engineering educators (Alqassab et al., 2023), reflecting the hypothesis that various assessment tasks set in engineering disciplines may be easily objectively evaluated (Li et al., 2016). Such assessment tasks may include those in which a known set of theoretical formulations are used in a predefined way to find a final quantitative answer. However, other more open-ended tasks, such as engineering design with several possible approaches and infinitely many solutions, may require more experienced assessors with a wider and deeper understanding of the discipline than students.

You may wish to consider starting with formative PA for more complex tasks, before introducing a summative element as students develop greater confidence and feedback literacy. In many cases, a combination of both approaches can work well, using PA during the development of work to support learning, and incorporating peer judgement into the final evaluation to promote accountability.

Transparency: anonymous or open PA

As a practitioner, one of the key design decisions you will face is whether peer assessment is anonymous or openly attributed. Anonymous PA encourages more honest feedback and reduces anxieties around social pressure amongst students. Open feedback can promote accountability and encourage more thoughtful and constructive comments. The most appropriate approach will depend on your cohort size, the nature of the task, and students' prior experience with PA. For example, anonymous feedback may work better in larger cohorts or early in a programme, while open feedback may be more appropriate more experienced groups where trust has been established.

Structure: reciprocal, intragroup, or intergroup

In reciprocal assessment, students review each other's work in pairs or small groups. In intragroup assessments, students evaluate the contributions of members within their own teams. In intergroup assessment, students review work produced by other groups. Each structure has its benefits and may be more suitable for particular activities; e.g., reciprocal assessment can work well in small classes or seminar-style activities where students exchange feedback on each other's work and discuss it directly. Intragroup assessment is commonly used in teamwork settings where students evaluate the contributions of members of their own group, often to support a fairer distribution of marks. Intergroup assessment can expose students to different approaches to the same task and encourage comparison and critical reflection across groups.

Stage: draft work vs. final submission

PA may be used during the development of work, e.g. reviewing draft reports or preliminary design, or applied to final submissions. Reviewing of drafts often emphasises formative feedback and supports iterative improvement, while assessing final submissions may be more closely linked to summative evaluation. This is further discussed in example 1, featuring PA of draft work in a final-year capstone project.

By integration: peer-only vs. self-and-peer

PA naturally involves an element of informal self-assessment, as students compare their own work with that of their peer, which can help develop independent and reflective learners. Indeed, the comparable impact of peer assessment and self-assessment on academic performance has been shown in the literature (Double et al., 2020, Yan et al., 2022). To potentially reinforce its impact, self-assessment can be formally integrated in any peer assessment model. More information about self-assessment can be found in Chapter 3.2 in this Handbook.

While traditional PA offers significant benefits, the challenges around engagement, mark reliability and feedback quality have led to the development of more advanced methodologies. The 360PA and IPAC approaches, described in sections 3 and 4, directly address many of these limitations.

3 The 360PA assessment method (PA of a product and feedback)

3.1 Motivation

Despite the general benefits of the traditional PA for students, its practical implementation presents various challenges, as discussed above. In general terms, traditional PA has two stages: in stage 1 the students submit their work, and in stage 2 the students assess the work of one or more of their peers. The specific implementation will vary depending on practitioner's choices, but in most of the cases the students' final mark comes exclusively from the quality of the work (the product) that they submitted in stage 1, as recorded in the review by Yan et al. (2022). Despite the strong benefits of engaging with the PA part of the process (stage 2), many students perceive this stage as constituting significant extra work with limited tangible

benefit, leading to low levels of buy-in and engagement with this stage. This compromises the validity of grades and quality of the feedback. However, making students accountable and including the assessment of the quality of peer feedback is shown to improve the engagement of the students and the quality of the feedback and peer score (Camarata & Slieman, 2020; Patchan et al., 2018). This is formally done for example in the 360-degree PA (360PA) methodology developed at University College London (UCL), Faculty of Engineering, in collaboration with the UCL Institute of Education (Garcia-Souto et al., 2017). Since its introduction, the method has been implemented across a range of engineering activities and has continued to operate successfully improving student engagement and quality of feedback.

3.2 What is 360PA?

The 360PA method extends the traditional PA and follows the process outlined in Fig. 3.2.1. It encourages students to engage with the peer review process and to produce meaningful evaluations, awarding marks based on the quality and accuracy of the feedback that they provide. Therefore, it constitutes a PA of both the submitted product and the feedback generated by the students.

In the 360PA method students first submit a piece of work, i.e., a product (stage 1). Next, they assess a selection of their peers' submissions (stage 2), typically using a structured rubric that defines the criteria against which feedback should be provided, helping ensure consistency and quality across reviewers. Afterwards, they review and evaluate the feedback they received based on tutor-provided criteria (stage 3). Tutors intervene if students highlight inaccuracies or issues when evaluating feedback received, ensuring that moderation is targeted and efficient.

Students' final marks reflect both the quality of the product they first submitted, and the feedback they provided, with the balance between these two elements representing a key decision for the practitioner. Some educators prefer to place greater emphasis on the product (submitted in stage 1) while still acknowledging the effort in stage 2, for example using a 70-30% split. Alternatively, the PA activity can also be designed to focus exclusively on the critical evaluation of a peer's work and the construction of professional, relevant feedback, with all marks allocated to stage 2, as illustrated in example 1 in Section 5 of this chapter.

3.3 Benefits of the 360PA methodology

The 360PA method builds on the recognised benefits of the traditional PA approach outlined in section 2.1, while addressing many of its limitations. The benefits described below are drawn from our experience of implementing this methodology at UCL (Garcia-Souto et al., 2017) and are consistent with broader principles of effective PA design, particularly the importance of structured processes and iterative feedback cycles (Adachi et al., 2018; Fleckney et al., 2025).

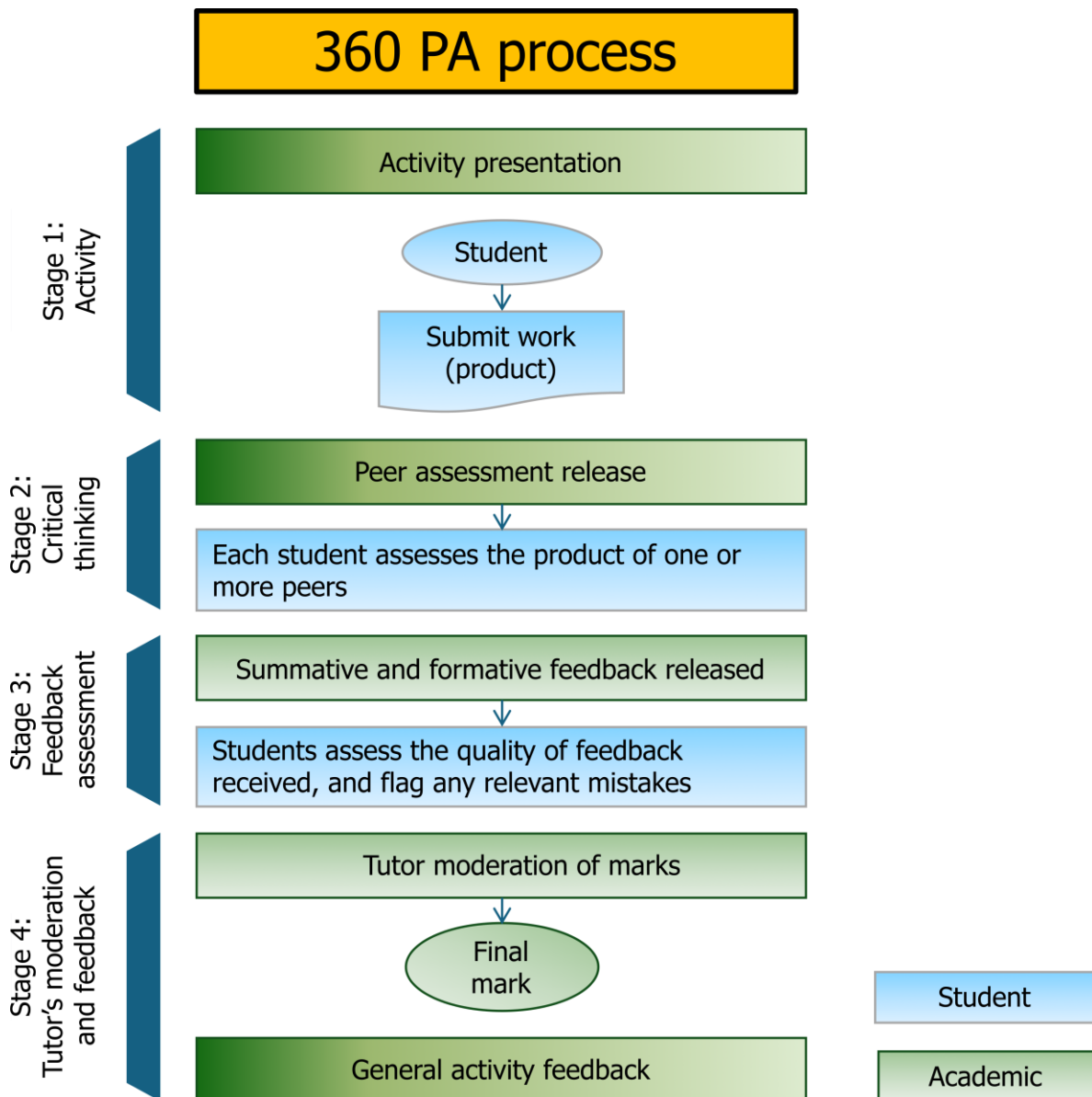


Figure 3.2.1: 360 degrees PA methodology (360PA) developed at UCL, © 2018 Pilar Garcia-Souto, used with permission, no further use allowed.

Increased engagement with the peer review process

The 360PA methodology embeds incentives such as marks for active participation, motivating students to complete the PA stage, and addressing a major difficulty observed in traditional PA, where many students fail to complete their reviews, thus disrupting the PA process.

Increase of the quality of the feedback

Similarly, students are motivated to provide high-quality feedback in their peer reviews, as this directly impacts the grade they receive. This improvement has been

reported by staff as well as by students, who now perceive the feedback they receive as more useful, with fewer instances of disagreement. Providing students with clear standards and criteria to guide the review process supports greater consistency and enhances the quality of feedback (Adachi et al., 2018).

Greater engagement with received feedback

Feedback only benefits learning when students actively read and reflect on it, which is not always the case. The 360PA model requires students to evaluate the feedback they receive, thereby, ensuring engagement and encouraging careful consideration of how it applies to their own work.

A standard process for raising concerns

The method embeds an expectation and formal mechanism for reporting incorrect or inappropriate feedback, which triggers tutor moderation. This reduces student anxiety and enhances trust in the marks and feedback received, addressing a key limitation of traditional PA. Notably, significantly fewer issues are reported under the 360PA model.

Further self-regulation

As students assess the quality and accuracy of the feedback they receive (numerical scores and written comments), they are required to reflect on how this feedback relates to their work and how to act on suggested improvements. This also helps them to develop a clearer understanding of what constitutes effective feedback.

4 The IPAC assessment method

4.1 Motivation

One specific application of PA broadly used in higher education, and in engineering in particular, is the PA within teamwork. In this case, PA is implemented to mark and/or provide feedback regarding member contributions in learning scenarios where students work in teams towards a set objective. This Individual PA of Contribution to group work (IPAC) method (Garcia-Souto, 2019) reflects a broad pedagogical shift towards active learning, student agency, and teamwork.

4.2 What is the IPAC methodology?

The conceptual implementation of IPAC is simple (Fig. 3.2.2). Students work together in a team and complete a tangible outcome defined and assessed by the tutor, e.g. a presentation, a report, an engineering design, etc., leading to a shared 'team mark'. The students then assess themselves and their peers, considering the level of contribution and professional competencies with students obtaining an IPAC value after tutor moderation. Both scores are then combined such that each student receives an individual final mark based on the overall tutor-assessed team achievement and their individual participation as perceived and assessed by their peers. Garcia-Souto et al. (2019) and Yang et al. (2022) describe several modalities through which the IPAC methodology can be implemented, while Thite et al. (2024) reviews and proposes relevant rubrics.

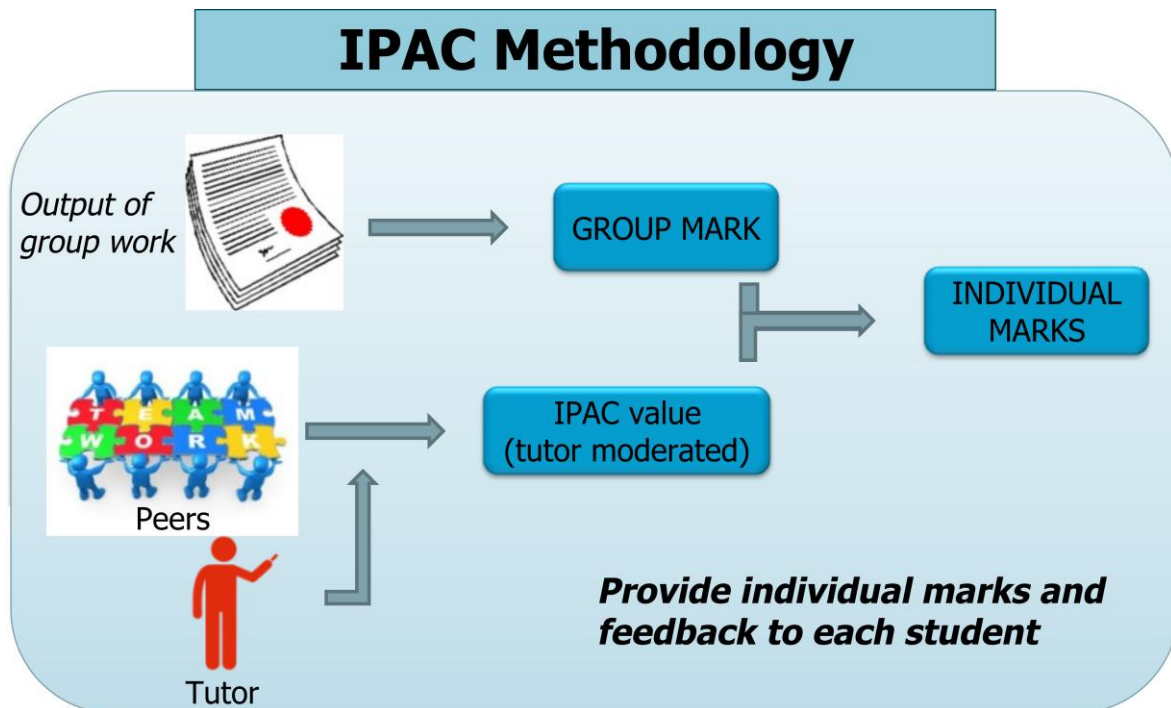


Figure 3.2.2: IPAC methodology © 2018 Pilar Garcia-Souto, used with permission, no further reuse allowed.

4.3 Benefits of the IPAC methodology

There are numerous benefits associated with the IPAC methodology that align with those of the traditional PA. In addition, it addresses and mitigates many of the significant challenges commonly encountered in the management and assessment of teamwork, as shown by the practice at UCL Engineering (Garcia-Souto et al., 2024a) and other institutions (Garcia-Souto et al., 2024b). Some of these benefits are:

- Fairer evaluation of individuals, accounting for their contribution to the team using a formal and standard approach;
- Greater engagement and improved professional behaviour following accountability to peers;
- Valuable check point for staff and students, particularly useful mid-project, even for formative purposes;
- Development of feedback literacy and transferable competences such as teamwork and self-regulation.

The flexibility of the IPAC methodology is another distinct advantage, allowing educators to tailor its implementation to suit the specific learning objectives of an activity and the developmental stage of their students. For example, it can be used in earlier years with short projects to assess level of contribution and improve engagement; or in later years with more substantial projects to assess professional competencies once students have developed more feedback literacy (see example 2 in Section 5 of this chapter). The IPAC methodology is generally welcomed by students

(Grammenos et al., 2019) and significantly reduces the number of students' complaints about free riding students and about their own marks. Nevertheless, some queries about low IPAC scores usually arise, leading to more educational staff-student discussions. Furthermore, the students' IPAC scores obtained in prior activities can be used to inform the grouping strategy in subsequent activities (Garcia-Souto, 2025). The IPAC methodology should be supported by training for students in good teamwork competencies and professional behaviour. Furthermore, staff should provide moderation when required.

4.4 Tools for the IPAC methodology

Implementation of the IPAC methodology without an appropriate system is logistically challenging and very time-consuming. There are several tools to implement this methodology e.g., the IPAC system developed at UCL (IPAC, n.d.), WebPA developed at Loughborough University (WebPA, n.d.) and CATME (Purdue University, n.d.) in the US.

5 Competencies associated with implementation and practical examples

Implementing PA, whether for individual products or team-based processes, can support the development of students' transferable competencies and skills such as feedback literacy, teamwork (see also Chapter 2.6), interpersonal communication, collaborative engagement, professional communication, self-reflection, and self-regulation (Chapter 2.13).

By engaging with feedback as a dialogue, where both receiving and giving occur in iterative cycles (see example 1), students develop critical judgement and self-reflection (Adriell, 2025). In developing feedback literacy (See also Chapters 2.11 and 2.12), you as an educator play a key role in guiding students and scaffolding the process through effective learning design (Carless & Boud, 2018).

When engaging in PA, students must move beyond technical critiques and address the social dimension of learning, where communication and interpersonal relations (Chapter 2.10) are essential. Through reviewing and providing feedback, they develop awareness of expectations, quality and standards, alongside perspective taking (Cruz et al., 2013). Presentation skills (see also Chapter 2.7), including verbal communication, audience interaction, and time management, can also be improved through peer assessment (Alba-Flores et al., 2019). Your role as an educator remains crucial in designing opportunities for students to practise reviewing, writing, listening, and speaking while enabling perspective taking.

As noted in this handbook, learning in engineering is also often a group endeavour. In teamwork-based activities, the inclusion of PA of each individual's contribution, such as the IPAC methodology offers (see example 2), provides a structured framework for professional communication and the development of competences related to team processes. Students may need to address uneven contributions or breakdowns in collaboration, fostering accountability and team spirit, and supporting a community of

practice, as shown in example 2 and Oakley et al. (2004). This supports students in navigating team dynamics in a safe manner by recognizing diverse contributions and maintaining a shared commitment to team goals.

Finally, PA generally encourages self-reflection through iterative assessment and feedback loops. In preparing to give feedback, students identify gaps in a peer's work, compare this with their own and adjust their learning accordingly (Ortega-Ruipérez & Correa-Gorospe, 2024; Yan et al., 2022).

Example 1. Use of 360PA in the final year to improve feedback literacy and individual research products

The 360PA method has been implemented for over a decade in the Research Skills module taken by all undergraduate students in the Department of Medical Physics and Biomedical Engineering at UCL. This module prepares students to plan, execute, and communicate their individual capstone research project.

The primary aim of embedding 360PA is to support the production of high-quality communication outputs for final assessment, including (1) an oral presentation; (2) a research poster; and (3) a selected section of the written report. For each component, students submit a draft that undergoes the 360PA process. Summative marks for the 360PA activity are awarded solely on the feedback they provide as assessed by peers based on tutor-provided criteria that include quality and usefulness of the feedback. Students then use this feedback to refine their work and prepare the final submission that is assessed by staff as part of their research project.

The implementation of the 360PA method has demonstrated several significant benefits in the context of the research skills module:

- *Earlier engagement and improved preparation. "Pushes" students to produce drafts in advance, reducing last-minute work and enabling reflection and refinement;*
- *Consistent, meaningful, and timely feedback for all. All students receive similar and prompt feedback following the scheduled peer assessment activity, reducing variability arising from differences in supervisory input;*
- *More focused supervisory workload. Centralising communication-related feedback frees supervisors to concentrate on higher-level technical guidance;*
- *Peer benchmarking. Reviewing peers' work helps students better understand expected standards and situate their own performance.*

Example 2. Using IPAC to support accountability, teamwork, and leadership development in a multidisciplinary MEng design project

The final year multidisciplinary MEng design project at Swansea University is a substantial 40-credit project involving Mechanical, Electrical, and Materials Engineering students working together in teams from October to May to identify, develop, prototype, and evaluate an engineering solution to a real-world problem.

Students work collaboratively across the project while also leading specific work packages or technical areas.

The IPAC assessment methodology is used twice during the project and contributes 25% of the overall module mark. The first IPAC activity is formative and takes place following a major project milestone, allowing students to reflect on teamwork, communication, engagement, and leadership within the group. The second IPAC activity is summative and takes place at the end of the project. The summative IPAC score is used to differentiate individual student marks within the group project, allowing the final module mark to better reflect individual contribution and professional engagement within the team. The same IPAC questionnaire is used on both occasions, featuring questions related to the stated aims.

Through the IPAC process, students reflect upon and score both their own contribution and that of their peers, while also receiving and providing constructive feedback. In many cases, the feedback is positive and reassuring, helping to build confidence, particularly among quieter or less confident students. In other cases, the feedback identifies areas where improvement is required, and students are encouraged — with support from educators where necessary — to interpret and respond to the feedback.

The repeated use of IPAC throughout the project promotes accountability, engagement, and reflective professional practice within the team.

6 Recommendations for implementation

We have shown that PA, in its various modalities, offers significant benefits to engineering education. It is particularly useful when used to foster progressive learning across a programme, such that students develop feedback literacy (giving and receiving feedback), teamwork skills, and other competencies like communication and self-regulation. In this section we give you guidance and advice to implement PA in either of the two major modalities, i.e., (1) assessing a product and the quality of the feedback produced by students (a mixture of the traditional and 360 degrees PA modalities); and (2) assessing the contribution of peers within a team project. Tutor moderation should always remain part of the process to ensure students' acceptance.

6.1 Recommendations for implementation of PA of product and feedback quality

In traditional PA, when students assess a product, we recommend you use the 360PA method, presented and discussed in section 3. This approach encourages students to engage meaningfully with the PA part of the process, creating higher quality feedback for their peers, which in turn is recognised through higher marks. You should also consider what exactly your students should assess, since the benefits of assessing specific points and the students' capability to assess these will differ. We recommend the assessment focuses on the elements outlined below, with an intended progressive development of relevant competences:

The structure and effectiveness of communication. Students can assess this from an 'expert' perspective since they typically represent the target audience for these pieces and can judge if they are presented in a way they can understand. Students will feel capable to give an opinion on this, mitigating a challenge in traditional PA.

Transferrable technical understanding. This should refer to principles and reasoning skills that are applicable across a wide range of contexts, rather than knowledge that is highly specific to a particular project or field. Examples include formulating a clear research question, ensuring that results and conclusions address that question, presenting graphs and tables that successfully aid the reader, and critically evaluating whether the narrative of discussion is coherent and supported by the evidence, without requiring students to judge field-specific accuracy of the data itself. By focusing on these aspects, you enable students to progressively build critical, analytical, and evaluative competences that are valuable in any scientific or engineering context. You also help to prevent a major challenge in traditional PA, namely that students are often sceptical of their own ability and that of their peers to critique work in a specialised field, since their knowledge is limited.

6.2 Recommendations for implementation of PA within teamwork

You can implement the IPAC methodology explained in section 4 in various ways, based on the specific activity, its learning objectives, and the developmental stage of your students. However, certain foundational recommendations can enhance the effectiveness and consistency of the IPAC assessment process, as listed and discussed by Garcia-Souto et al. (2019). Some of these guidelines are:

- *Must.* Inform students from the outset that the IPAC methodology will be used, along with clear expectations regarding professional behaviour, and that tutor moderations will apply.
- *Valuable.* Ask students to provide feedback that justifies the scores given — this provides valuable insights for staff on team dynamics.
- *Valuable.* Make the IPAC assessment more valuable to students by giving each individual their anonymized feedback (summative and formative assessment).
- *Valuable.* Run an IPAC assessment midway through a project for formative purposes, particularly in longer projects where early feedback can support team development.

We observe that student accountability achieved via the use of IPAC is an effective way of promoting student engagement and professionalism within team projects of any kind. It also provides practitioners with a clear view of team dynamics and a formal record that can support timely intervention when necessary. The development of skills via the IPAC methodology is more impactful in longer projects where students have more time to interact with the other team members. It is also enhanced over the years as students gain experience and encounter more extensive and sophisticated peer feedback in longer projects at later stages of their degree.

6.3 Generative artificial intelligence considerations

GenAI has introduced significant opportunities and challenges in higher education, and its transformative nature is likely to drive further changes as it continues to develop. A full discussion of these implications, including those for PA, is beyond the scope of this chapter. However, several key considerations are worth noting.

There is evidence that, for some students, feedback co-generated with generative AI (GenAI) may be perceived as more effective than peer feedback alone (Noel et al., 2025). In addition, long-standing challenges in PA, such as consistency and fairness in marking, may be addressed more efficiently through AI-assisted assessor training and moderation processes (Topping et al., 2025).

At the same time, GenAI tools have made it more difficult to maintain the integrity of several established assessment formats, creating a need for adaptation of these formats (Francis et al., 2025). PA is no exception, and practitioners must reflect on how it is used in this evolving context. One approach is to ask students to critically evaluate GenAI outputs, particularly where these outputs fall short in accuracy or quality. For example, a comparative case study found that GenAI often awarded higher grades than human assessors and sometimes produced contradictory or irrelevant feedback (Usher, 2025). Encouraging students to critically evaluate such inconsistencies can be a valuable component of PA. However, as prompting practices improve and models evolve, this approach requires regular review.

A longer-term response may be to strengthen the focus on competency-based education and iterative forms of assessments (Francis et al., 2025). Iterative engagement, alongside the development of feedback literacy (provision and receipt), embeds local context within the assessment. This creates a requirement for reflection and revision that cannot be met through over-reliance on GenAI alone.

7 Summary

We leave you with the following take-home messages. You can use PA to support student learning and self-confidence especially thorough progressive implementation in the programme, developing feedback literacy (giving and receiving feedback), communication competencies, self-assessment practices, and teamwork competences. We suggest that if you implement PA of a product (a piece of work), you should also include the PA of the quality of feedback, i.e., similar to the 360PA, since this will encourage students' participation and increase quality of the feedback. In teamwork activities, we suggest you use the IPAC methodology that makes students accountable to peers and addresses some of the challenges when running and assessing teamwork. When using PA, you need to introduce student training, incorporate tutor moderation, and use a system for implementation. PA remains valuable even in the GenAI era, since it supports students' development. GenAI presents opportunities but also challenges, particularly for assessment integrity, that need to be considered.

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AI statement

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3.3

Self-Assessment in Engineering Education

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This chapter presents self-assessment as a practical strategy for learning and professional formation in engineering education. Rather than self-grading, self-assessment is framed as a structured, criteria-based process that helps students monitor their strategies, evaluate their work, and plan improvement. For practitioners, this chapter offers ready-to-use tools, including exam wrappers, reflexive prompts, and developmental rubrics, along with fully worked examples applicable across knowledge-based and design-oriented modules. It addresses common implementation challenges, such as faculty beliefs, time constraints, and student scepticism, and emphasizes rubrics, exemplars, guided practice, and explicit calibration with instructor feedback as essential supports. By embedding self-assessment intentionally, educators can better align technical performance with reflective judgement, professional responsibility, and long-term adaptability.

1 Introduction: why self-assessment matters

Self-assessment has become an increasingly important practice in engineering education as programmes move beyond viewing it solely as a grading mechanism and adopt more student-centred, outcomes-based approaches (Litzinger et al., 2011; Panadero et al., 2018). Self-assessment is a structured, criteria-based process in which students evaluate their work, monitor their progress, and identify strategies for improvement (Boud & Falchikov, 1989; Yan & Brown, 2017). Because it parallels professional practices such as design reviews, troubleshooting, and performance evaluation, self-assessment connects classroom learning with the reflective, ethical, and technical dimensions of engineering practice (Turns et al., 2014).

When embedded intentionally, self-assessment contributes directly to core transferable competencies and skills identified in the SEFI framework. It strengthens self-regulation by requiring students to monitor their strategies and performance, cultivates self-reflection as they analyse reasoning and feedback, and promotes self-direction by shifting responsibility for improvement from instructor to learner. Structured self-assessment also supports the development of effective learning strategies by helping students replace ineffective habits with targeted approaches to problem solving. It fosters intrinsic motivation by emphasising growth and iteration rather than judgement alone. Through these mechanisms, students calibrate their understanding, respond constructively to feedback, and build habits of intentional improvement (Schunk, 2011). Over time, these practices contribute to professional identity formation, resilience, and adaptability in the face of complex and uncertain engineering problems (Bonilla & Findley, 2024; Trevelyan, 2010). When framed carefully, they can also affirm diverse ways of demonstrating growth, amplify student voice, and promote more equitable participation in engineering classrooms (Nieminen, 2022; Sellers & Villanueva, 2023).

This chapter examines self-assessment in engineering education through three lenses. First, it defines the concept clearly and distinguishes it from related practices such as self-reflection, self-monitoring, and self-evaluation (Yan & Brown, 2017). Second, it explores three core approaches (post-exam self-assessment tools, reflective and reflexive practices, and rubric-based self-assessment) and considers when and why each may be most effective. Third, it discusses practical implementation strategies that support sustainability, alignment, and refinement in diverse engineering contexts (Mannion, 2022; Yucel et al., 2014). In doing so, the chapter illustrates how it functions in practice and demonstrates how you can embed it to strengthen both learning and professional identity formation.

In this chapter, reflection refers to looking back to analyse outcomes, reasoning, or emotional responses, often with the aim of identifying lessons learned and strategies for improvement (Schön, 1983). Reflexivity refers to examining positionality, values, and institutional or social context, with attention to how these factors influence problem framing and design choices (Cunliffe, 2016).

2 Defining self-assessment

Self-assessment is a structured process in which students use explicit criteria to evaluate their work, reflect on their progress, and identify strategies for improvement. At its core, self-assessment requires three elements: clear criteria, evaluative judgement against those criteria, and a feedback loop that informs revision or future action. Without these elements, activities may support reflection, but they do not constitute self-assessment in the sense used here.

Because the term is often used loosely, it is important to distinguish self-assessment from related processes. Terms such as self-reflection, self-monitoring, and self-evaluation are sometimes used interchangeably, yet they serve distinct purposes and vary in their connection to learning outcomes (Panadero, 2017; Taras, 2010). This chapter adopts a focused definition of self-assessment, excluding practices that lack explicit criteria, clear evaluative purpose, or a mechanism for feedback and revision (Boud & Molloy, 2013; Yan & Carless, 2022). Table 3.3.1 summarises these distinctions and clarifies the boundaries of what is included in our use of the term.

Table 3.3.1: Distinguishing self-assessment from related processes and misconceptions

<i>Self-assessment is...</i>	<i>Self-assessment is not...</i>
A formative or summative process using explicit criteria to evaluate learning, reflect on progress, and guide improvement (Boud & Falchikov, 1989; Panadero et al., 2018; Yan & Brown, 2017)	Self-grading or self-evaluation used solely to assign a score or judgement, without attention to growth (Andrade, 2019; Taras, 2010)
A cyclical, feedback-informed practice that draws on internal and external sources to support intentional change (Panadero et al., 2017; Yan & Carless, 2022)	A stand-alone self-report or activity disconnected from feedback, revision, or actionable next steps (Bourke, 2018; Yan & Carless, 2022)
A structured comparison of performance against criteria, followed by planning for future improvement (Panadero, 2017; Yan & Brown, 2017)	General reflection or awareness without structure, explicit goals, or evaluative criteria (Bourke, 2018; Taras, 2010)

3 Approaches to self-assessment in engineering education

Self-assessment can take different forms, depending on its purpose, timing, and level of structure. Rather than treating these as competing categories, it is more useful to consider how they complement one another. This section clarifies three distinctions that shape design decisions around self-assessment in engineering modules: process-

versus outcome-focused, formative versus summative, and structured versus open-ended approaches.

3.1 *Process- and outcome-focused self-assessment*

One key distinction concerns whether students are evaluating how they worked or what they produced. Process-focused self-assessment centres on strategies, problem framing, collaboration, and decision making during a task, and is particularly valuable in project- or challenge-based learning where progress unfolds iteratively (Boud & Falchikov, 2007). Outcome-focused self-assessment, by contrast, emphasises the quality of a completed product. Students compare their final work to defined standards, criteria, or exemplars. Although it captures less about the learning process, it strengthens evaluative judgement, an essential professional skill in engineering practice (Tai et al., 2018). In practice, these approaches are most powerful when combined. For example, in a design module, students might keep a reflective journal to examine their problem-solving strategies during the project (process-focused) and later use a rubric to assess their final prototype against professional criteria (outcome-focused).

3.2 *Formative versus summative self-assessment*

A second distinction concerns timing and purpose. Self-assessment is commonly used for formative purposes, helping students monitor their understanding, analyse progress, and make informed adjustments during the learning process (Panadero et al., 2018; Yan & Brown, 2017). Occurring before final submission, formative self-assessment supports revision by prompting students to identify strengths, diagnose gaps, and adjust their work, often in dialogue with instructor or peer feedback (Black & Wiliam, 1998). However, self-assessment can also serve summative purposes, such as when students evaluate their achievement at the end of a task, module, or milestone as part of a final portfolio or appraisal (Andrade, 2019). Even in these contexts, it remains developmental when students justify their evaluations and articulate next steps for improvement. For instance, students in a laboratory module might complete a mid-semester self-review to refine experimental techniques (formative) and later write a final self-assessment reflecting on their growth across the term (summative). The critical distinction, therefore, lies less in whether the task contributes to grading and more in whether it fosters evaluative judgement and forward-looking improvement.

3.3 *Structured and open-ended approaches*

Self-assessment also varies in its degree of scaffolding. Structured approaches, such as rubrics, checklists, or rating scales, provide explicit criteria and a consistent framework for judgement (Panadero & Jonsson, 2013). These tools are especially useful in large modules or multi-instructor settings, where transparency and alignment are priorities. Open-ended self-assessment, such as journals and reflective narratives, allow students to explore their reasoning and experiences in their own words. While they can bring deeper insights to light, they often require guidance to ensure that reflection moves beyond description toward evaluation and planning (Wallin & Adawi,

2018). In a capstone modules, for example, students might use a rubric to assess technical criteria (structured) and write a brief reflection on team dynamics or design trade-offs (open-ended).

Table 3.3.2: Approaches to self-assessment in engineering education

<i>Approach</i>	<i>What it is</i>	<i>When you might use it</i>
Post-exam self-assessment tools	Structured activities after exams that prompt students to analyse their preparation, identify error patterns, and plan specific improvements (e.g., exam wrappers, guided error analysis) (Panadero et al., 2017; Yucel et al., 2014).	Particularly effective in exam-based modules (e.g., statics, circuits, thermodynamics) where you want students to move beyond grades to diagnose misconceptions, refine study strategies, and build resilience (Yan & Brown, 2017; Zimmerman & Schunk, 2011).
Reflective and reflexive practices	Prompts or assignments that require students to examine their learning processes, reasoning, assumptions, and the broader context of engineering decisions (e.g., reflective writing, reflexive memos) (Bourke, 2018; Turns et al., 2014).	Most effective in project- and design-based modules where technical, ethical, and social dimensions intersect and where adaptive expertise and professional identity are central learning goals (Nieminen, 2022).
Rubric-based self-assessment	Developmental rubrics with explicit criteria and performance levels that prompt students to evaluate their work, justify ratings, and identify next steps (Panadero et al., 2018).	Useful across knowledge-based and process-oriented modules, especially where transparency, alignment with competencies, and iterative improvement are priorities (Mannion, 2022; Yucel et al., 2014).

4 Implementation in engineering programmes

The impact of self-assessment depends less on the concept itself and more on how it is designed, scaffolded, and embedded in a course. This section translates the preceding distinctions into practical approaches that you can adopt and adapt. It highlights three complementary approaches commonly used in engineering education: post-exam self-assessment tools, reflective and reflexive practices, and rubric-based self-assessment. Each serves a distinct purpose and aligns with different module structures, assessment types, and professional competencies. Rather than treating

these as alternatives, they can be combined strategically across a programme. Together, they support the development of self-regulation, self-reflection, self-direction, learning strategies, and autonomous motivation, while also strengthening technical judgement and professional responsibility. Table 3.3.2 provides an overview of each approach and when it may be most effective.

These approaches are also feasible in large cohorts (e.g., 150-250 students) when they are designed to minimise additional marking and administrative burden. For example, exam wrappers and brief reflective activities can be implemented using standardised prompts and structured response templates, and assessed using low-stakes, completion-based credit focused on the presence of a concrete action plan rather than the quality of the narrative. Similarly, rubric-based self-assessment can remain manageable when students are asked to self-rate only selected criteria and provide brief, evidence-based justifications, while you calibrate expectations through exemplars and periodic sampling or spot-checking of submissions. Peer-supported processes (e.g., structured peer assessment aligned to the same rubric) can further distribute feedback work, allowing instructor input to focus on recurring patterns and targeted whole-class guidance. Where available, learning platforms can support efficient collection, aggregation, and analysis of responses, enabling you to provide feedback at the level of common needs rather than extensive individual commenting.

4.1 Post-exam self-assessment tools

Exams in engineering education are often treated as final checkpoints, i.e., summative assessments marking the end of a learning unit. When paired with structured follow-up activities, however, they can become powerful learning events. Post-exam self-assessment tools invite students to revisit their performance, analyse patterns of error, and identify specific strategies for improvement. In doing so, they shift attention from “*What grade did I receive?*” to “*What does this performance reveal about how I prepared and how I should adjust?*” This shift supports self-regulation by prompting students to monitor their strategies, strengthens learning strategies by making preparation habits explicit and revisable, and fosters autonomous motivation by framing mistakes as data for growth rather than evidence of fixed ability. In a discipline where iteration and troubleshooting are central, post-exam reflection mirrors professional engineering practice.

Post-exam tools in action

Post-exam self-assessment can be brief and low-stakes or more structured and analytical. Three adaptable approaches are described here.

Exam wrappers. Exam wrappers are short reflections completed after an exam. They prompt students to examine how they studied, identify recurring error types, and commit to specific changes before the next assessment. For example, in thermodynamics, wrappers can help students recognise that memorising equations is insufficient for solving multi-step problems which require identifying system boundaries, applying conservation principles, and interpreting property tables. This

realisation often leads students to shift away from passive review to targeted problem-solving practice.

Guided reflection prompts. Guided prompts move beyond right-wrong analysis by asking students to examine their reasoning. Typical questions include “*Where did your reasoning diverge from the expected approach?*”, “*What misconception influenced this answer?*”, and “*How would you approach a similar problem differently?*” Such prompts are most effective in modules where conceptual reasoning and problem framing are central, such as statics, circuits, mechanics, or systems modelling. They are particularly useful when you want students to explain why an approach was flawed rather than simply identify that it was incorrect. By emphasising explanation over categorisation, guided reflection strengthens evaluative judgement and disciplinary thinking, while also strengthening students’ ability to articulate reasoning in collaborative engineering contexts.

Error typologies. Structured error analysis asks students to categorise mistakes (e.g., conceptual misunderstanding, misreading, calculation error, time management) and identify likely causes. Unlike exam wrappers, which prompt broad reflection on preparation strategies, error typologies focus specifically on diagnosing patterns within the exam itself. They are most effective when you observe recurring misconceptions or want students to distinguish between surface errors and deeper conceptual gaps. In a digital systems module, for example, students may initially label errors as ‘calculation mistakes’, only to realise the root cause was misinterpreting constraints or working under time pressure. Recognising these distinctions enables more targeted preparation and reinforces a key professional norm: engineers diagnose underlying causes, not just outcomes. Error typologies are especially useful in large, exam-heavy modules where you want structured insight into common errors across cohorts.

A worked example from practice

In a second-year statics and dynamics module (approximately 50 students), the third author introduced structured exam wrappers after the first midterm. Historically, students attributed poor performance to vague explanations such as ‘careless mistakes’ or ‘not enough revision’. The wrapper was designed to prompt specific diagnosis and planning. Students completed the reflection during the first ten minutes of the next class and received completion credit (2% of the module grade). Two weeks later, they submitted brief evidence of one strategy they had implemented (e.g., annotated practice problems or a revised study plan). Their responses were analysed for recurring patterns, and part of the next class session was devoted to addressing the three most common misconceptions. Within two exam cycles, students’ plans became more specific, fewer attributed performance to fixed ability, and preparation strategies aligned more closely with the cognitive demands of exam questions.

Example 1. Post-exam reflection template

This example fits early-stage undergraduate, exam-based engineering modules (e.g., first- or second-year statics, circuits, thermodynamics) where you want students to use exam performance to diagnose misconceptions and adjust study strategies before the next assessment.

1. *Two types of errors I made most frequently:*
 - ☐ *conceptual misunderstanding*
 - ☐ *misreading the question*
 - ☐ *calculation error*
 - ☐ *time management*
 - ☐ *other: _____*
2. *Example and root cause:*
 - ☐ *on what question did you make an error? (Select one.)*
 - ☐ *what specifically went wrong?*
3. *How I prepared for this exam (mark all that apply):*
 - ☐ *reread notes*
 - ☐ *solved practice problems*
 - ☐ *studied with peers*
 - ☐ *other: _____*
4. *One strategy that did not work well — explain why.*
5. *One strategy I will change before the next exam — be specific.*
6. *One resource I will use, e.g., office hours, tutoring, study group.*

This structure can be readily adapted to other exam-based modules (e.g., circuits, mechanics, materials) by tailoring the error categories, prompts, and follow-up expectations to align with local learning goals and assessment formats.

Embedding post-exam self-assessment effectively and equitably

Students' exam experiences are shaped by prior preparation, cultural expectations, and access to support systems (Yan & Carless, 2022). Without careful framing, reflection activities may reinforce deficit narratives or fixed-ability beliefs, particularly when performance is interpreted as a signal for who is 'cut out' for engineering (London et al., 2011; Tonso, 2006). Post-exam self-assessment should therefore position mistakes as a normal and expected part of learning and professional engineering practice. Just as design involves testing, iteration, and revision, exams can be reframed as part of that same developmental cycle.

Post-exam self-assessment tools are most effective when they promote equity while also informing both student action and instructional decisions.

To support student learning and equitable participation, you can:

- Normalise error as expected in engineering practice;
- Model reflective thinking by analysing a common mistake and demonstrating a revision (Metcalf, 2017);
- Invite contextual reflection, allowing students to note factors affecting preparation (e.g., workload, employment, access to study space) (Bang & Vossoughi, 2016);
- Require specific, feasible action before the next assessment, not general intentions, to ensure reflection leads to action;
- Include a brief follow-up checkpoint to reinforce implementation;
- Emphasise improvement rather than performance alone, for example by grading for completion rather than accuracy and allowing private submission.

To strengthen instructional practice, you can:

- Review reflections for recurring misconceptions or strategy gaps;
- Share patterns with the class and adjust instruction accordingly;
- Periodically revisit exam format, pacing, or feedback, if misalignment persists.

When embedded consistently, post-exam reflection cultivates an iterative learning culture. Students learn to analyse mistakes and implement changes; you gain insight into student thinking, and exams become part of a developmental cycle rather than isolated endpoints.

4.2 Reflective and reflexive practices

Project- and design-based modules are well suited for reflection and reflexivity because students must collaborate, make decisions under uncertainty, and justify trade-offs in ways that resemble professional engineering work. When structured intentionally, these practices help students improve their technical decision making and examine how values, assumptions, and context shape design outcomes (Kim et al., 2019). As a result, reflection and reflexivity can strengthen adaptive expertise, helping future engineers navigate ambiguity while remaining ethically and socially aware (Fisher & De Rosa, 2021).

Distinguishing reflection and reflexivity

In this chapter, reflection refers to looking back to analyse outcomes, reasoning, or emotional responses, often with the aim of identifying lessons learned and strategies for improvement (Schön, 1983). Reflexivity refers to examining positionality, values, and institutional or social context, with attention to how these factors influence problem framing and design choices (Cunliffe, 2016). Reflection supports metacognitive growth and technical learning, while reflexivity presses students to ask why they approached a problem in a certain way and how their assumptions or biases shaped outcomes. Research shows that engaging in both practices consistently and with purpose helps students articulate their learning and take ownership of their growth (Thomson & Kövesi, 2023).

Embedding reflection and reflexivity into modules

Reflection and reflexivity can be embedded through activities that help students examine their learning processes and the broader contexts of their work. Together, reflection and reflexivity foster a more complete form of learning that advances technical competence while cultivating ethical responsibility, social awareness, and professional identity development (Hirsbrunner et al., 2024). The following strategies describe how these practices can surface insights, challenge assumptions, and connect technical decisions to ethical and social considerations in engineering:

Reflective writing prompts. You can use guided prompts in design- and project-based modules to help students surface implicit assumptions, connect disciplinary values to broader societal needs, and develop technical discernment over time (Cosgrove, 2022). For example, you can ask for weekly reflections in a capstone module in which students (1) identify key moments of insight, tension, or challenge; (2) explain how their thinking evolved or was challenged during the project; and/or (3) connect module content to prior experiences and personal beliefs.

Reflexive memos. You can use reflexive memos to ask students to examine a specific design decision by identifying the assumptions and disciplinary norms that shaped it and considering the consequences for different stakeholders (Boyd, 2023). If you integrate these memos at key project milestones, you can strengthen students' capacity to recognise and engage with the social justice dimensions of engineering work, supporting them to become more socially responsive practitioners (Boyd, 2023; Nelson et al., 2024). For instance, in a biomedical engineering module, you can ask students designing a portable insulin delivery device for children to reflect on how assumptions about a 'typical' child user shaped their design, how values influenced trade-offs between cost, reliability, and comfort, and how prototype feedback revealed overlooked perspectives that led them to revise their decisions.

Grade for specificity and insight, not for virtue or personal disclosure. In your grading, reward clear evidence, explicit articulation of assumptions, and concrete changes to the design or process. Explicitly state that students will not be evaluated on the perceived 'correctness' of their values or feelings — i.e., their 'virtue' —, but on the quality of their reasoning and the way they use reflection to improve decisions.

Deepening reflexivity: examining assumptions and decisions

While these strategies provide accessible entry points, you can help students develop deeper reflexivity by explicitly examining the assumptions that shape their decisions. Reflection is most powerful when treated as a practice of meaning-making, asking not only what happened, but why choices were made and whose perspectives they represent (Figard & Mercado, 2023). One framework that supports this deeper engagement is Sochacka et al.'s (2009) three-tier model of reflexivity, originally developed for engineering education research but easily adapted for student projects. It prompts learners to (1) examine their ontological and epistemological assumptions by asking what counts as knowledge and who has the authority to define it; (2) acknowledge the influence of personal values by situating practice in broader social,

institutional, and historical contexts; and (3) reflect on how prior experiences shape their choice of methods and tools.

Applied in design modules, this framework helps students recognise how decisions about 'good' usability may rely on hegemonic norms or how trade-offs (e.g., cost vs. accessibility) reflect assumptions about the 'typical' user. Mapping design choices back to these tiers allows learners to gain insight into how positionality shapes the engineering process. Cunliffe (2016)'s concept of 'critical reflexivity' deepens this stance by emphasizing the ongoing, disruptive questioning of how engineers come to know, think, and act. When projects involve community stakeholders, sustainability goals, or global development challenges, the stakes of unchecked assumptions become especially high (Cain et al., 2023).

Implications for engineering education

Reflection and reflexivity function as critical forms of self-assessment within engineering project and design modules. Activities such as guided writing or reflexive memos ask students to evaluate how their perceptions, values, and decisions shape their work. When learners articulate what informed a technical choice, they are assessing their own mental models and the guiding principles that shaped their reasoning (Olewnik et al., 2024). This process helps students surface unconscious biases, refine problem framing, and consider the broader social implications of their designs. Over time, they develop the metacognitive skills needed to address ill-structured engineering problems (Marra et al., 2022; Wengrowicz et al., 2018), the capacity to judge their own reasoning, adjust assumptions when evidence or ethics demand it, and approach future projects with a more reflexive mindset. Over time, reflective and reflexive practices support stronger problem framing and growth as thoughtful, socially responsive engineers equipped for lifelong professional learning (Fisher & De Rosa, 2021; Kim et al., 2019).

4.3 Rubric-based self-assessment

Rubric-based self-assessment can strengthen learning when they are used as tools for guidance and revision, instead of solely as scoring sheets. By making expectations explicit, rubrics help students judge their current work against shared criteria, identify what to improve, and plan concrete next steps (Boud, 1991). This is especially useful in project and active-learning settings for connecting conceptual knowledge with professional competencies (Dochy et al., 1999). In general, rubrics align well with engineering practice, where progress is iterative, feedback-rich, and tied to professional standards.

From outcomes to developmental growth

Traditional assessments can signal performance as a final verdict, which makes it harder for students to see how improvement happens. Rubric-based self-assessment addresses this by describing progress as a continuum (e.g., Beginning, Emerging, Proficient, Advanced) and making growth visible over time. When students use the same rubric repeatedly across assignments or iterations, they can track change, set goals, and build motivation through evidence of progress. In engineering, this

approach mirrors professional practice because engineers routinely evaluate work against criteria, identify gaps, and revise based on feedback.

Rubric-based self-assessment practices

The following practices describe how rubrics can support progress monitoring, align evaluation with learning goals, and connect student development to professional competencies in engineering:

Tie the rubric directly to learning goals and show how it will be used. Align criteria with the outcomes students are expected to demonstrate and refer to the rubric during instruction, not only at grading time. For example, in a knowledge-based master module, criteria might assess students' ability to apply theoretical concepts to real-world scenarios, emphasizing integration of knowledge, critical analysis, and application in societal contexts. In a project module, criteria can emphasize decision-making process, stakeholder reasoning, and iteration. In both cases, rubrics serve as scaffolds that help students frame their reflections and connect performance to broader module goals.

Treat the rubric as a tool for tracking progress across time. Use the same rubric at multiple points in a project or across several assignments and ask students to identify one criterion they improved and one they will target next. This shifts the rubric from a one-time evaluation to a developmental record of learning. Research further shows that when students engage with rubrics consistently and with purpose, they are better able to reflect on their development and take greater ownership of their progress (Panadero & Jonsson, 2013). In a knowledge-based module, for instance, students might begin by acknowledging gaps in understanding but gradually articulate greater confidence in applying theoretical frameworks and critically evaluating their work. In project-based modules, reflections may reveal more dynamic and nonlinear trajectories, as students adapt strategies through experimentation, feedback, and shifting roles within teams.

Justify decisions and learn from feedback. Rubrics are most powerful when students are required to justify their ratings rather than simply selecting a level (Andrade & Valtcheva, 2009). Providing evidence from coursework, projects, or team interactions fosters metacognitive awareness by prompting students to analyse strategies, recognise progress, and plan next steps. In knowledge-based modules, students might justify their ratings by explaining how they applied theoretical frameworks and evaluating their effectiveness. In project-based modules, justifications are often narrative, including reflections on teamwork, stakeholder engagement, and professional identity development.

A worked example from practice

In several project-based modules (all with approximately 35 students), the first author introduced rubric-based self-assessment. Students assessed themselves several times during the module based on their development on the module's learning objectives. This self-assessment consisted of completing a rubric and writing a short justification. The rubric could be scored on process-based levels, see also Example 2. Interviews

with students showed that this process allowed them to take ownership of their own learning and helped them understand what to do to further develop their skills.

Example 2. Rubric-based self-assessment

This example illustrates how a developmental rubric can guide student self-assessment in project-based engineering modules. Students use the rubric multiple times to evaluate how their reasoning, collaboration, and decision-making evolve over time.

This example fits mid- to late-stage undergraduate project and design modules where teamwork and iterative decision making are assessed over multiple milestones; it can be adapted for master-level project modules with similar iterative cycles.

Each criterion includes multiple developmental levels that are consistent with growth-oriented assessment approaches. Students are asked to (1) select the level that best represents their current performance; and (2) provide a short justification for why they chose that level. Instructors require students to revisit the same rubric later in the project. Students highlight shifts in their level (e.g., Emerging → Proficient) and explain what supported that growth.

Table 3.3.3: This table shows the levels for the learning goal "Students are able to communicate and collaborate with people from other disciplines".

Beginning	Emerging	Proficient	Advanced
<i>I mostly communicate from my own disciplinary perspective, and I struggle to explain ideas in ways others can easily follow. I often need help noticing or resolving communication challenges.</i>	<i>I am starting to adjust my language so teammates and stakeholders can understand me. I can spot communication challenges, but I'm not yet consistent in addressing them.</i>	<i>I communicate clearly across disciplines and adapt my wording to fit different audiences. I collaborate effectively, understand others' contributions, and address communication issues constructively.</i>	<i>I anticipate communication challenges and tailor my approach to different disciplines and stakeholders. I help the team align perspectives and support others in navigating complex communication situations.</i>

Embedding rubric-based self-assessment into modules

Rubric-based self-assessment can be embedded through activities that help students evaluate their development over time and make sense of their learning. When framed

developmentally, rubrics offer students a clear pathway for growth and help them connect their ongoing work to broader professional competencies. These practices foster metacognition, strengthen evaluative judgement, and support the formation of self-directed learning habits. The following strategies illustrate how rubric-based self-assessment can guide students in identifying progress, planning next steps, and engaging more deeply with engineering learning:

Use developmental levels aligned with module timepoints. Developmental labels such as 'Beginning', 'Emerging', 'Proficient', and 'Advanced' help students understand that growth occurs across the duration of a module rather than at a single evaluative moment. Asking students to self-assess at multiple points (such as early in a project, mid-module, and at the end) helps them recognise patterns, articulate shifts in their thinking, and plan targeted improvements.

Incorporate multiple measures to make growth visible. Providing repeated opportunities to complete the same rubric encourages students to track changes in their approach, strategies, and confidence. Multiple measures also allow you to track how students perceive their learning with what is demonstrated in their work, supporting more accurate self-evaluation and helping students develop stronger metacognitive awareness.

Embed a feedback loop on completed rubrics. When students submit rubrics alongside their work, you can respond to both the product and the student's interpretation of their progress. Brief comments, discussion prompts, or calibration conversations help students refine the understanding of their growth and development over time. This feedback loop reinforces rubric use as part of an ongoing learning cycle rather than a stand-alone activity.

Rubrics can clarify expectations, but they can also unintentionally privilege narrow forms of demonstration if descriptors are vague or rely on implicit norms. Students from diverse backgrounds may interpret vague descriptors differently or feel constrained if criteria privilege narrow ways of demonstrating knowledge. Clarity of descriptors is therefore essential; concrete examples at each level help students see what performance looks like in practice (Jonsson & Svingby, 2007). Alignment with module goals is equally important. Present the rubric as a guide for improvement and invite multiple forms of evidence for meeting criteria, especially in process-oriented outcomes such as collaboration, communication, and design reasoning. Making expectations explicit in this way supports students who may otherwise be disadvantaged by hidden curricula (e.g., first-generation students) (Garriott & Nisle, 2018; Sellers & Villanueva, 2023).

Supporting reflection is another key consideration. Structured prompts, examples, and timely feedback help students move beyond surface-level observations toward deeper analysis (Boud & Molloy, 2013). At the same time, you must manage practical challenges such as workload and calibration. Because reviewing self-assessments can be time-intensive, digital tools and peer feedback can help sustain the practice while ensuring students receive guidance. Calibration activities, such as co-creating rubrics

or reviewing sample reflections, not only improve reliability but also engage students as partners in the process, reinforcing equity and ownership. When rubrics are designed with these considerations in mind, they support accurate and meaningful self-assessment while also fostering belonging, affirming diverse strengths, and cultivating the reflective habits needed to thrive in engineering education and practice.

Implications for engineering education

Rubric-based self-assessment functions as a critical tool for supporting learning and professional formation. By evaluating their progress against clearly defined criteria and justifying their ratings with evidence, students engage in metacognitive practices that help them recognise patterns in their thinking, refine problem-solving strategies, and plan concrete next steps (Andrade & Valtcheva, 2009). This process fosters resilience and adaptability, encouraging students to view learning as iterative rather than fixed, while also connecting academic assessment to professional competencies such as collaboration, stakeholder engagement, and ethical responsibility. For you as educator, rubrics provide diagnostic insight into how students interpret expectations and respond to feedback, making implicit standards explicit and supporting more equitable learning environments (Jonsson & Svingby, 2007). Over time, consistent use of rubric-based self-assessment cultivates both technical competence and the reflective habits of mind necessary for adaptive expertise, positioning engineering students to grow as accountable, socially responsive professionals prepared for lifelong learning (Brookhart, 2013; Panadero & Jonsson, 2013).

5 Implementation considerations

While self-assessment offers clear benefits, effective implementation requires intentional design. Students may resist these activities if they perceive them as peripheral to technical work or unclear in purpose. Concerns about judgement, confidence, or accuracy can further shape participation. Research consistently shows that novices tend to overestimate performance, while stronger students may underestimate it, underscoring the need for calibration and guided practice (Dunning & Kruger, 1999; León et al., 2021).

You may face parallel challenges, including time constraints, grading pressures, and uncertainty about how to scaffold reflective practices effectively. Your own beliefs as an instructor also influence student uptake, with some viewing self-assessment as central to professional formation, while others question its reliability or instructional value (Andrade, 2019; Yan, 2020). These realities highlight a central principle: self-assessment must be explicitly aligned, scaffolded, and embedded within feedback cycles to be meaningful.

Table 3.3.4 summarises how the approaches discussed in this chapter contribute to selected competencies and what observable evidence you might expect in practice.

Drawing on both research and practice, the following considerations outline strategies for embedding self-assessment in engineering modules.

Align self-assessment with module goals. Self-assessment is most effective when clearly tied to learning objectives. Prompts and rubrics should reflect the language and priorities of the module, so students recognise them as integral rather than peripheral. For example, in thermodynamics or circuits, an exam wrapper might ask students to identify where and why points were lost, linking errors to specific conceptual gaps. In an environmental engineering capstone, a reflexive memo might require students to move beyond listing sustainability factors and instead analyse how material, energy, and disposal considerations interact within a broader system. In both cases, alignment reinforces authenticity and professional relevance.

Table 3.3.4: Self-assessment and relevant competencies

<i>Competency</i>	<i>How self-assessment develops it</i>	<i>Observable evidence in modules</i>
Self-regulation	Students monitor strategies, diagnose errors, and plan concrete improvements (e.g., through exam wrappers and rubric-based review).	Students identify specific learning gaps and submit action plans; improved strategy use over time.
Self-reflection	Structured prompts and reflexive memos require students to articulate reasoning, assumptions, and growth.	Written reflections that identify strengths, limitations, and revised approaches.
Self-direction	Repeated self-assessment tasks shift responsibility for improvement from instructor to student.	Students set learning goals, track progress across milestones, and independently seek resources.
Autonomous motivation	Emphasizing growth and iteration reframes assessment as development rather than judgement.	Increased persistence after setbacks; reflective planning rather than grade-focused responses.
Learning strategies	Post-exam tools and rubric use make study and problem-solving strategies explicit and revisable.	Students replace ineffective strategies (e.g., cramming) with targeted practice and planning.

Scaffold for accuracy and engagement. Self-assessment is a skill that develops with guided practice. Rubrics, exemplars, and modelling help students learn what evaluative judgement looks like before applying it independently. In exam-based modules, you can model wrapper completion by analysing a sample solution and demonstrating how to diagnose reasoning breakdowns. In design-based modules, students may begin with structured reflexive prompts and gradually move toward

more independent reflection. Similarly, rubric-based self-assessment benefits from calibration exercises, such as comparing self-ratings with instructor feedback and discussing discrepancies. Scaffolding should therefore involve modelling, structured examples, and iterative feedback, not simply providing answers.

Integrate self-assessment with instructor feedback. Self-assessment complements, rather than replaces, instructor feedback. Asking students to submit reflections or rubric ratings alongside their work creates opportunities for calibration and dialogue. For example, a student reviewing a statics exam may express confidence in free-body diagrams but identify difficulty with combined loading; instructor feedback can clarify assumptions and direct targeted practice. In design contexts, persona development may reveal overlooked user groups, prompting discussion about broader stakeholder needs. When self-scores and instructor scores diverge, structured discussion supports accuracy and shared standards. Embedded with a feedback cycle, self-assessment strengthens evaluative judgement and reinforces that improvement, not self-judgement, is the goal.

6 Conclusions: toward a culture of reflective growth

Self-assessment is more than an instructional technique; it is a practice that shapes how engineers learn, adapt, and develop. When intentionally designed, it helps students evaluate their work honestly, recognise strengths and limitations, and treat feedback as a resource for improvement rather than judgement. Over time, these habits strengthen self-regulation, reflective judgement, and strategic learning, capabilities that prepare students for professional practice.

Beyond individual assignments, self-assessment links learning to identity formation and social responsibility. By asking students to articulate their reasoning and growth, it reinforces agency and acknowledges that competence develops through iteration. Framed carefully, self-assessment can also support equity and belonging by positioning growth, not innate ability, as central to engineering success.

The challenge is not whether to use self-assessment, but how consistently and intentionally to embed it. When integrated across modules through post-exam tools, reflective practices, and rubric-based evaluation, it becomes a part of the learning culture rather than an add-on activity. In this way, reflection, calibration, and feedback literacy stand alongside technical mastery as defining features of what it means to think and act as an engineer. Embedded within curricula and supported by thoughtful design, self-assessment extends beyond a method of evaluation to become a foundation for sustained professional growth.

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3.4

Assessment Rubrics: Design, Development and Implementation

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This chapter examines the design, development, and implementation of assessment rubrics as practical tools for evaluating transferable skills in engineering education. Transferable skills are complex, context-dependent, and often assessed through authentic tasks such as projects, laboratory work, teamwork, and professional communication, making consistent and transparent assessment challenging. Rubrics address this challenge by articulating expectations through explicit criteria and performance standards, thereby supporting fairer and more consistent judgement. The chapter introduces foundational concepts underpinning effective rubric use, including evaluative criteria, performance levels, and scoring strategies, and distinguishes between commonly used rubric types such as holistic and analytic rubrics. It discusses how rubrics can be applied for formative and summative assessment purposes, highlighting their roles in supporting feedback, learning, and assessment reliability. This chapter also offers a step-by-step, practitioner-oriented guide to rubric development. This guide addresses purpose clarification, alignment with learning outcomes, criteria formulation, performance-level description, and iterative refinement through feedback and assessor calibration. Examples drawn from engineering education illustrate how rubrics can be designed and implemented to assess transferable skills within authentic assessment contexts.

1 Introduction

Assessing a transferable competency or skill is difficult. These skills are often complex and context-dependent and they may require forms of assessment other than exams or similar tests. Because of their complexity, expectations of how a task involving these skills is executed well may differ between a student and an assessor - or even within a group of assessors themselves. It requires some effort to develop a framework that supports more reliable and less subjective assessment of these skills. Rubrics address this need by translating complex performance expectations into explicit, structured criteria.

A rubric can be defined as a tool that articulates expectations for student work by listing assessment criteria and describing levels of performance along a continuum of quality (Brookhart, 2018). In the context of engineering education, rubrics are commonly used to assess complex and authentic tasks such as design projects, laboratory reports, teamwork, and professional communication.

Rubrics are also particularly well-suited for assessing transferable skills. These skills are not always directly observable and are demonstrated differently across contexts. Therefore, assessors need a common reference point to judge performance consistently and transparently. By making expectations explicit, rubrics enable students to better understand and improve their skills. The clarity of a rubric promotes learning: in an analysis of studies addressing rubrics and performance, Brookhart and Chen (2015) concluded that rubric use is generally associated with increased student achievement.

Second, as a feedback tool, a rubric can be used by experts to assess the quality of a student's work, but also by students themselves to assess their own work. Regarding the latter, well-designed rubrics improve self-regulated learning, as students use rubrics as reference point to assess their work in progress (Panadero & Jonsson, 2013).

Third, as a grading tool, rubrics are commonly associated with improved inter-rater reliability (consensus between assessor) and intra-rater reliability (consistency from an individual assessor). Jonsson and Svingby (2007) found that the use of rubrics can support more consistent scoring, particularly when agreement is measured across adjacent performance levels rather than exact scores.

Despite their many benefits, the use of rubrics has been criticised (see Panadero & Jonsson, 2020, for an overview of criticisms). For one, rubrics are alleged to fragment complex skills into smaller chunks, essentially asking assessors to focus on "*the parts, rather than the whole*" (Panadero & Jonsson, 2020, p. 8). Similarly, sharing explicit criteria with students may steer students to 'criteria compliance'; and their lack of expertise may make it difficult for students to understand the criteria (Panadero & Jonsson, 2020).

Many criticisms and problems associated with rubrics boil down to poor rubric construction (Oakleaf, 2009). When the wording in a rubric is too general, for example,

it may not be clear to rubric users how to interpret specific criteria. In turn, this may hinder student learning or reliable assessments. On the other hand, when the wording in a rubric is too specific, a rubric may indeed lead to criteria compliance. This means that the rubric is tailored to a very specific assignment, which will not help students in learning how to apply their skills in different settings. In fact, a very explicit task-specific rubric may restrict students to conformity, excluding an innovative 'out of the box' response to the task (McKenna, 2007).

Developing a workable rubric takes time and thought. Rubric development should be informed by the learning outcomes that an assessment task is intended to evaluate. At programme level, learning outcomes articulate the overarching knowledge, skills, and graduate attributes students are expected to develop, while module-level outcomes specify how these are addressed within individual modules. For rubric design, it is sufficient that criteria are explicitly aligned with the relevant module learning outcomes associated with the assessment task.

To make this process easier, this chapter introduces a step-by-step guide to construct a rubric. To do so, Section 2 defines the term and discusses rubric types (holistic or analytic) and their focus (general or task-specific). Then, Section 3 details the role of rubrics in engineering education, detailing their relation to quality standards, assessment procedures, and feedback. In this regard, common pitfalls are discussed that may hinder an optimal use of a rubric. Section 4 shows best practices in developing rubrics, which includes the step-by-step guide in Section 4.1 and a checklist in Section 4.2. Section 5 shows examples of rubrics in engineering education.

2 The role of rubrics

A rubric is an assessment tool used to assess the quality of student work by defining criteria and describing levels of performance in relation to those criteria. In engineering education, rubrics are particularly valuable for assessing transferable skills within complex, authentic tasks that involve judgement and multiple assessors. In practice, rubrics may serve multiple purposes: they may be task-specific or used across a module or programme; applied formatively or summatively; and used by tutors, peers, or students themselves for self-assessment. Clarifying the intended purpose of a rubric is a critical first step in its design.

By making assessment expectations clear, rubrics help students understand performance standards, provide structured and actionable feedback, improve the efficiency and consistency of marking, and may help reduce differences in outcomes between student groups by making assessment decisions more transparent and less subjective.

2.1 Structure of effective rubrics

Rubrics are visualised as tables composed of rows, columns, and cells and usually include three essential features: (1) criteria for evaluation, which specify the aspects of performance being judged; (2) performance levels, which describe gradations of quality for each criterion; and (3) a scoring strategy, which explains how judgements

are translated into feedback or grades. Criteria define 'what' is being assessed, while performance levels describe 'how well' it has been demonstrated.

In Fig. 3.4.1, the rows of the table represent assessment criteria aligned with the intended learning outcomes, while the columns represent different levels of performance (for example, from inadequate to excellent). The cells at the intersection of rows and columns contain qualitative descriptions that define what performance looks like at each level for each criterion, and, where appropriate, indicate associated scores or weightings. This structured visualisation enables both assessors and students to interpret expectations consistently and transparently.

For a rubric to be effective, it is important that the basics are in place, understood, and aligned (Dawson, 2017). The development of assessment criteria should be grounded in well-aligned programme-level and module learning outcomes, allowing educators to select assessment tasks that meaningfully support student development and demonstrate achievement of those outcomes. In engineering education, such tasks should be designed to assess higher-order thinking skills, such as analysis, synthesis, and evaluation, rather than focusing solely on the recall of information (Biggs & Tang, 2011). In doing so, assessments provide opportunities for students to demonstrate progress toward institutional graduate attributes.

Assessment criteria should clearly communicate the specific aspects of the deliverable that will be evaluated in relation to the intended learning outcomes. Developing these criteria and the associated qualitative performance-level descriptors benefits from collaboration among educators to ensure shared standards and consistent interpretation. In addition, involving students in the design of rubrics can further enhance transparency, foster a shared understanding of expectations, and support deeper engagement with the assessment process (Andrade & Du, 2005).

How performance levels are defined may depend on the use of a rubric. Rubrics designed for grading often assign a weight to particular criterion or performance level as part of a scoring strategy (Popham, 1997). When a rubric is used summatively, performance levels may be defined with a numerical descriptor (e.g., '*1 point*' and '*4 points*', as in Fig. 3.4.2). Rubrics can also be used in formative assessments, in which a verbal descriptor may make more sense. These descriptors can be generally evaluative (e.g., '*poor*', '*sufficient*', and '*good*'); they can qualify the student (e.g., '*novice*', '*apprentice*', and '*expert*'), qualify their process (e.g., '*getting started*', '*well on your way*', and '*as good as done*'); there are indeed many other possibilities.

2.2 Types of rubrics in engineering education

In engineering education, two main rubric types are commonly used: holistic rubrics and analytic rubrics. The choice between these depends on the nature of the learning outcomes, the assessment task, and the type of feedback required.

Holistic rubrics

Holistic rubrics are often used when one complex skill or multiple related skills are assessed as one. For example, if students of maritime technology develop a ship in a

certain project, the main question in the assessment may be: does it actually do what it is required to do? Despite the complex nature of such a project — which includes skills such as mathematical modelling, spatial reasoning and applying structural mechanics — the entire project is assessed in one single criterion.

As such, a holistic rubric in this project may include the ship’s functionality, its design, and other features, but these features are assessed as one. A prototypical holistic rubric can be found in Fig. 3.4.1 and its pros and cons in Table 3.4.1. Holistic rubrics are well-suited for summative assessment and tasks focusing on overall performance, such as examinations.



Figure 3.4.1: Example of a holistic rubric illustrating the relationship between criterion, standards, and descriptors (Own Work)

Table 3.4.1: Pros and cons of holistic rubrics

Pros	Cons
Fast and easy to apply	Offers minimal specific feedback on components
It is quicker to mark student work (fewer decisions for markers)	Unable to assign importance to individual criteria
Can be consistently applied across graders once trained	It can be difficult to understand how each criterion is weighted
The final mark represents a holistic judgement of the student’s progress against all specified learning outcomes.	

Analytic rubrics

An analytic rubric includes multiple specific criteria which together form the assessment of a task. For example, when the same students of maritime technology must present their ship in an oral presentation or a written report, these tasks may be assessed on clarity, on style, storyline, and so forth. Each of these individual criteria is assessed separately as part of the task.

A prototypical analytic rubric format can be seen in Fig. 3.4.2 with criteria being the rows in the table, performance levels the columns, and performance level descriptions the individual cells. The performance level descriptions clarify what counts as a specific level in a specific criterion.

	← Performance levels →		
Criterion 1			
Criterion 2			
⋮			
Criterion <i>n</i>			

Descriptors

Figure 3.4.2: Example of an analytic rubric illustrating the relationship between criterion, standards, and descriptors (Own Work)

Analytic rubric with criteria that vary in numerical weight

A weighted rubric assigns a specific percentage or a higher point value to certain criteria to reflect their importance, e.g. with criterion A contributing 10% to the grade, criterion B 25%, criterion C 20%, etc. Table 3.4.2. shows the pros and cons of analytic rubrics with criteria that vary in weight. These types of rubrics are well-suited for summative assessment and tasks focusing on overall performance, such as reports, presentations etc.

Table 3.4.2. Pros and cons of analytic rubrics that vary in weight

Pros	Cons
It is transparent how the final grade is reached	Time-consuming to design and use
Allows for easier assessment of measurable features	It can place disproportionate emphasis on things that are easy to measure, like grammar, spelling, formatting, or citation style. ('halo effect', see Sadler, 2009)
Able to weight criteria to emphasise key learning outcomes	It can disadvantage multilingual students or those with different academic writing backgrounds, even if they meet core learning outcomes
It is easier to assign the same grade to work of equivalent quality	

Analytic rubric with criteria that have the same numerical weight

With this rubric, every criterion carries the same mathematical weight, e.g., five criteria of 20% each. The pros and cons of such a rubric are shown in Table 4.4.3. These rubrics are well-suited for summative assessment and tasks focusing on overall performance, such as peer assessment, self-reflection etc.

Table 3.4.3: Pros and cons of analytic rubrics with equal weight

<i>Pros</i>	<i>Cons</i>
The final grade reflects the work as a whole	Time-consuming to design and use
Provides specific feedback across criteria	Can be problematic if some aspects of the work are more important than others, because all criteria contribute equally to the final mark
Focus is placed on student performance, not scores for each criterion	Too many unweighted criteria may dilute focus or over-partition of tasks

2.3 General and task-specific rubrics

Besides different types, rubrics can also differ from each other when it comes to focus: some rubrics are designed to assess a specific assignment, whereas other rubrics are aimed to skills. This is where the difference between general and task-specific rubrics comes in.

General rubrics assess the performance of a particular skill, such as writing, designing, or solving mathematical problems. By being more general, the same rubric can be used multiple times in a curriculum if the same skill is assessed in different tasks or modules. For example, if a student has to write technical reports in several modules, they might be assessed with the same rubric. In this way, students will be able to understand what it means to be good at a particular skill, and they learn what to expect when performing a task that requires this skill.

A task-specific rubric is geared towards a particular assignment. If we use the same example of students writing a report, a task-specific rubric may include a criterion like 'justification of bio-inspired design'. This criterion is very specific to the assignment, and the rubric therefore cannot easily be used in other contexts. Despite this drawback, task-specific rubrics may make it easier to assess a deliverable, as it allows the assessor to focus on specific elements in a specific task.

In both types, finding the right balance between specific and general is key. If a rubric becomes too specific, they might lead to conformity (McKenna, 2007). For example, if the rubric of a design project details per step of the process what the criteria for quality are, this may hinder students' creativity, and they may falsely assume that all design processes follow the same steps. Additionally, an assessor may not know what to do in an overly specific rubric if they encounter something that was not foreseen by the rubric.

Conversely, if a rubric is too generic, it may lose its value as a didactical instrument. Students may find the rubric too vague and do not know what to do with it. This can

be a problem for assessors too, as a rubric that is too general provides insufficient instruction on how to assess certain behaviour.

3 Context

The use of rubrics in engineering education is supported by a growing body of evidence highlighting their benefits for consistency, transparency, and learning (Cockett & Jackson, 2018; Panadero & Jonsson, 2020). Well-designed rubrics can support fairer marking across assessors, clarify expectations for students, structure formative feedback, increase marking efficiency, and contribute to reducing awarding gaps by limiting subjective judgement. However, these benefits depend on careful alignment between rubric design, assessment purpose, and implementation practices.

For this reason, before developing a rubric in engineering education, educators should address two important questions: (1) what impact is the rubric intended to have; and (2) what is the specific purpose of this rubric? Considering impact involves reflecting on issues such as fairness, reliability among assessors, and the effects of the rubric on student learning and engagement. Purpose, in contrast, relates to how and when the rubric will be used, for example whether it is intended for summative grading, formative feedback, or both. These different purposes may require different design choices; a summative rubric, for instance, may prioritise workability and consistency, whereas a formative rubric may place greater emphasis on explicit guidance and developmental feedback.

3.1 *Impact of rubrics*

When developing rubrics in engineering education, there are two main stakeholders to take into account: students and (fellow) assessors. A rubric should be clear in order for an assessor to assess the students' work and has to be clear for the students in order to know what is expected from them in terms of quality of their deliverable. To that end, there are certain things a rubric can do, but certainly also things a rubric cannot do.

Most importantly, when rubrics result in a specific score or grade, it can never offer a perfect representation of a skill. Still, when the rubric is well-designed, the score will be a good approximation of that skill. This difference may seem trivial, but many mistakes in developing rubrics can be prevented when priorities are set straight. For example, a common pitfall in making rubrics is to overload them with too many criteria, which may stem from the urge to make a rubric complete instead of effective. A rubric should not be an overview of everything that can potentially go right or wrong in each task.

Equally, when an assessor awards a maximum score to a student based on their scoring rubric (100%, 10 out of 10, etc.), it does not mean that a student has nothing to learn and that their work was perfect. Instead, it means that there was not that much more that reasonably could have been expected of the student given the specific task in a specific context. A high grade acknowledges a student's performance, but they might have scored differently on a different or more complex task.

Ultimately, a rubric serves as an instrument to manage expectations, as if it were an agreement between assessors and assessees on what counts as a good performance of the evaluated skill. In this light, one of the main aims of a rubric is to make it easy to justify a particular assessment — whether it is formatively or summatively — based on observable, relevant and explicit criteria.

A rubric used for grading should also reflect agreement between assessors. Assessing works by a larger student population often requires a team of assessors rather than just one. It would be unfair to students if the same work would receive significantly different grades if they were assessed by different assessors. This means that ideally, when asked to do so, each assessor needs to arrive at the same grade as their peers when they grade the same assignment, to ensure that each grade is fair and not dependent on whoever graded the task. In other words: a rubric should enhance inter-rater reliability.

Research in the inter-rater reliability of rubrics is largely context-specific, focusing on particular rubrics used by particular groups of assessors rather than comparing rubrics with alternative scoring methods. For example, Hansson et al. (2014) reported acceptable levels of inter-rater reliability and agreement when using a rubric to assess scientific writing. However, their findings relate only to that specific rubric and context and cannot be generalised to rubrics as a whole. Similarly, Oakleaf (2009) found that raters could achieve reasonable agreement when using a rubric to assess information literacy, but the study focused on differences related to assessor expertise rather than comparing rubrics with other assessment approaches. Together, these studies suggest that rubrics can support reliable assessment when carefully designed and implemented, but they do not provide evidence that rubrics are more reliable than other scoring methods such as checklists or rating scales.

Jonsson and Svingby (2007) reviewed studies that used rubrics and found that assessors often did not achieve the commonly used benchmark of 70% exact agreement, where two assessors assign precisely the same score to a piece of work. This suggests that perfect consistency between assessors is difficult to achieve, even when rubrics are used. However, they also found that studies measuring adjacent agreement, where assessors' scores differ by no more than one point on the rubric scale, frequently reported agreement rates above 90%. These findings indicate that, although exact agreement is uncommon, rubrics can still support a high level of consistency in assessment decisions.

There are strategies to mitigate problems relating to inter-rater reliability. The main strategy to ensure inter-rater reliability is to discuss assessment with fellow assessors. This can take many forms: a team of assessors can work together to create a rubric, for instance. This allows assessors to discuss what they find important in a skill and what should be prioritised. When there is already a rubric in place, assessors can calibrate scoring (Sadler, 2011). When assessors all assess the same work, compare their assessments, and discuss differences, they do not only reduce differences in their assessment, but they also become more confident in assessing students' work (O'Connell et al., 2015). For new assessors, a rater training may have this effect too.

Other strategies relate to the rubric design. For example, Jonsson and Svingby (2007) note that rubrics with fewer levels generally see higher agreement rates. Additionally, it may benefit assessors to provide explicit scoring guidelines. Examples or benchmarks may help new raters to see how they should use a rubric and how others would have assessed specific works. A potential pitfall in using these examples may be that they become outdated after a while. Generally, it is advisable to update rubrics, scoring guidelines, and examples regularly, to make sure that grading remains valid and reliable.

3.2 Purpose of rubrics

The design and application of a rubric vary on its purpose: rubrics can be used in formative assessment and in summative assessment. Summative rubrics are used to assess a deliverable (e.g., presentation, project, design, text). Typically, a summative rubric results in a grade of some sort, to indicate a student's performance. Formative rubrics are used during a module or in general: the learning process) to identify what goes well already and what needs to be improved.

As formative rubrics are aimed to give feedback on the learning process during a specific task, they need to be clear for students to be able to understand what they can improve and how. As always, the rubric should match learning outcomes and indicate whether students are on track to reach these learning outcomes. For this purpose, formative rubrics are usually very explicit.

Formative rubrics can be employed in a variety of learning activities. For example, students can give each other peer feedback with a formative rubric made by the lecturer. A fun, rather analytic activity is to co-create a rubric with students in class. This allows students to analyse the particular skill they will be learning and set goals for themselves.

A summative rubric should facilitate a valid judgement on a specific task. This judgement should reflect the quality of the performance and, by extension, the student's learning process. In summative rubrics, workability is a key criterion: the rubric should be easy to use for assessors, while still maintaining inter-rater and intra-rater reliability.

Summative rubrics should be shared with students from the start of a module, in order to manage expectations. This way, students can use the rubric throughout their learning process and have a clear understanding of what quality in a particular skill means. After assessing, filled out rubrics should also be shared with students to ensure transparency in grading.

4 Best practices for developing rubrics

Designing effective rubrics is a critical component of fair, transparent, and consistent assessment. Well-constructed rubrics not only support reliable marking but also enhance student learning by clarifying expectations and providing meaningful feedback. This section outlines best practices to guide educators through the process of developing high-quality rubrics; from defining their purpose to refining descriptors

through feedback. The practical steps presented here are grounded in pedagogical principles and aligned with institutional assessment standards.

4.1 Practical steps in rubric development

Step 1. Identify learning outcomes to be assessed

Identify which learning outcomes from the module will be assessed by the specific task or assignment. These outcomes should be clearly listed in the module specification.

Step 2. Define the purpose

First, decide what kind of rubric will be used, such as analytic or holistic, and whether it will give feedback in words (qualitative) or numbers (quantitative). If using numbers, the educator should think about the grade ranges used (for example, below 30%, 30-39%, 40-49%) and the words that describe each level (like 'fail', 'satisfactory', 'good'). It is a good idea to follow the same grade bands and language used in your institution's general assessment guidelines or the commonly used grading standards in your institution if formal guidelines are lacking.

Educators should also decide whether the rubric will be general or task-specific. This distinction influences how criteria and descriptors are written and how the rubric can be reused across assessments. In practice, educators may combine both approaches: using general criteria (such as analysis, communication, or application of engineering principles) while adapting descriptors to reflect the specific task context.

Step 3. Define the assessment criterion

The assessment criteria are the specific dimension of student performance that will be judged. Criteria are the essential features or attributes of student work that relate directly to the learning outcomes. They guide assessors in evaluating performance consistently and transparently and help students understand what is expected of them. Therefore, we recommend educators to:

- *Align with learning outcomes.* Criteria must directly reflect the specific module learning outcomes being assessed. Focus on what students should know, understand, or be able to do as a result of the learning experience.
- *Be clear and concise.* Criteria should be stated simply and unambiguously, for example 'knowledge and understanding', 'application of research skills', or 'use of evidence in argument'. If certain elements such as creativity, clarity of argument, or use of writing conventions (e.g., spelling, punctuation, grammar) are integral to the success of the task and its intended learning outcomes, they should be explicitly included as criteria.
- *One idea per criterion.* Each criterion should address a single skill, knowledge area, or attribute. Avoid combining multiple aspects (e.g., don't say 'critical and creative thinking' in one criterion).
- *Avoid quality judgements in the criteria labels.* Do not embed evaluative language (e.g., 'excellent', 'effective', 'well-developed') in the criterion itself. These should be reserved for the performance level descriptors.

- *Unpack complex criteria.* If a criterion seems broad or abstract, unpack it into more specific components or sub-attributes before defining performance standards. Ask: how, specifically, will the students demonstrate this learning outcome?

Step 4. Identify the threshold requirements

This step involves developing performance standards, which are clear descriptions of the different levels of quality that can be demonstrated for each assessment criterion. These standards form the basis for making informed and consistent judgements about student work. Performance standards describe how well the criterion has been achieved, as opposed to indicating whether a student has fully met a criterion. They outline observable and measurable differences in performance and are typically structured along a scale, such as '*excellent*', '*good*', '*satisfactory*', '*needs improvement*'. We recommend educators to:

- *Ensure clear progression across levels.* Each level should clearly distinguish what is expected. Avoid vague or overlapping descriptors.
- *Consistency.* Keep the number of performance levels consistent across criteria
- *Be specific to the context.* Write standards in a way that makes sense for the discipline, task type, and student level.

Step 5. Identify the standard descriptors

The standard descriptors articulate what performance looks like at different standards providing clarity and transparency for assessors and assesseees. They should outline the key characteristics of performance at each level clearly, be specific, and be achievable. Their purpose is to guide judgement, support feedback, and help students understand what is expected of them. Therefore, we recommend educators to:

- *Pitch standards at a reasonable level.* Descriptors should be challenging but achievable. Avoid setting the bar so high that few students can reach the top level, or so low that most students achieve the highest rating with ease.
- *Frame standards positively.* Describe what students should do at each level, rather than what they should avoid. This provides clearer direction and supports a growth-oriented learning environment.
- *Be specific but avoid over-precision.* Aim for specificity in describing performance but avoid unnecessary complexity or oversimplifying complex skills.
- *Define observable behaviours and qualities.* Use verbs that capture student actions (e.g., '*explains*', '*analyses*', '*applies*', '*identifies*', '*interprets*') and qualifiers or modifiers to define the level of achievement (e.g., '*some*', '*appropriate*', '*consistent*', '*limited*', '*comprehensive*').
- *Reflect higher-level thinking where appropriate.* At higher levels of achievement, descriptors may include additional cognitive demands, such as originality, depth of analysis, or metacognitive awareness (e.g., reflecting on one's own approach or reasoning).

Step 6. Get feedback

Rubric development is an iterative process, and initial versions often require adjustment. Trialling helps identify ambiguities, overlaps, inconsistencies, or unintended biases in criteria or standards. Calibration and moderation activities also enhance assessment reliability and consistency among assessors. Among the reasons to seek feedback and iterate rubrics:

- To ensure clarity and interpretability of descriptors.
- To assess whether the rubric reflects appropriate technical difficulty and is aligned with learning outcomes.
- To confirm that different assessors interpret the rubric similarly.
- To identify whether the rubric provides useful feedback to students.

4.2 Rubric development checklist

This checklist in Table 3.4.4 provides a structured guide for developing rubrics. It is designed to help ensure that all critical elements, such as purpose, criteria, performance levels, descriptors, and validity, are systematically addressed. Users are encouraged to review each item carefully, make necessary adjustments, and consider the rubric as an evolving tool that can be refined based on feedback and assessment outcomes.

Finally, rubrics should be viewed as evolving tools rather than fixed instruments. Regular review, informed by student performance data, assessor feedback, and changing disciplinary expectations, is essential to ensure that rubrics remain valid, inclusive, and educationally effective within engineering programmes.

Table 3.4.4: Rubric development checklist

<i>1. Define the purpose</i>
☐ Have I identified what the rubric will assess (e.g., project, presentation, essay)?
☐ Is the rubric aligned with learning outcomes?
<i>2. Determine the type of rubric</i>
☐ Have I chosen the most suitable format (holistic or analytic)?
☐ Does this format best support the assessment purpose?
<i>3. Identify assessment criteria</i>
☐ Have I clearly identified the key skills, behaviours, or knowledge areas to be assessed?
☐ Are criteria observable and measurable?
<i>4. Develop threshold requirements and standards</i>
☐ Have I defined the number of performance levels (e.g., as shown in step 4 'excellent' to 'needs improvement')?

-
- ☐ Are the performance levels clearly described and differentiated?
-

5. Write descriptors for each level

- ☐ Do descriptors for each criterion and level clearly explain the expectations?
- ☐ Are the descriptors specific, consistent in tone, and free from ambiguous language?
-

6. Review for validity and reliability

- ☐ Have I ensured the rubric measures what it intends to measure?
- ☐ Would different assessors interpret and apply it consistently?
-

7. Pilot and revise

- ☐ Have I tested the rubric with sample student work or in a trial run?
- ☐ Have I collected feedback and made necessary revisions?
-

8. Communicate with students

- ☐ Have I shared the rubric with students before the assessment?
- ☐ Have I explained how the rubric will be used to assess their work?
-

9. Reflect and improve

- ☐ Have I reviewed the rubric's effectiveness after use?
- ☐ Have I identified areas for improvement in future iterations?
-

5 Rubric examples

To illustrate the guidance provided within this chapter, below are examples of a holistic (Tables 3.4.5 and 3.4.6) and analytic rubrics (Tables 3.4.7-3.4.9). The aim of these rubrics is to evaluate the degree to which an assessment rubric supports and promotes skill development for learners being assessed and for educators using the tool to guide instruction and feedback.

Table 3.4.5: Example of a holistic rubric to assess the effectiveness of a rubric

<i>Criterion</i>	<i>Descriptor</i>
<i>Highly effective</i>	The rubric is a highly effective assessment tool. It clearly articulates performance criteria and levels with precise, discipline-appropriate language. It aligns directly with learning outcomes and promotes transparency, fairness, and consistency. The levels are distinct and progressive, allowing for nuanced feedback. The rubric supports formative and/or summative assessment, and it has been tested or reviewed for reliability and validity.

<i>Effective</i>	The rubric is a solid, functional tool for assessment. Criteria and levels are clear and generally align with learning outcomes. It enables fair and consistent evaluation with minimal ambiguity. There may be minor issues in clarity or redundancy, but overall, the rubric facilitates meaningful feedback and student understanding of expectations.
<i>Partially effective</i>	The rubric is functional, but its effectiveness is limited. Some criteria may be vague, overlapping, or misaligned with learning outcomes. Descriptors at performance levels may lack clarity or differentiation, making consistent scoring difficult. The rubric may offer limited support for learning and feedback. Revisions are needed to improve usability and fairness.
<i>Ineffective</i>	The rubric is ineffective or confusing as an assessment tool. Criteria are unclear, overly general, or unrelated to learning outcomes. Performance levels are indistinct or missing, making consistent evaluation impossible. The rubric is ambiguous and does not support constructive feedback. Significant redesign is required.

Table 3.4.6: Example of a holistic rubric to assess working in a team (from Rogers, 2010)

<i>Unsatisfactory</i>	<i>Developing</i>	<i>Satisfactory</i>	<i>Exemplary</i>
Does not collect any information that relates to the topic.	Collects very little information; only some relates to the topic.	Collects some basic information; most relates to the topic	Collects a great deal of information; all relates to the topic.
Does not perform any duties of assigned team role.	Performs very little of assigned duties. Rarely does the assigned work;	Performs nearly all assigned duties.	Performs all duties of assigned team role.
Always relies on others to do the work.	often needs reminding. Usually doing most of the talking; rarely	Usually does the assigned work; rarely needs reminding	Always does the assigned work without having to be reminded.
Is always talking; never allows anyone else to speak.	allows others to speak.	Listens, but sometimes talks too much.	Listens and encourages others to participate.

Table 3.4.7: Example of an analytic rubric that varies in weight to assess the effectiveness of a rubric. The numerical ranges shown within each performance level represent the number of points available for that criterion based on its weighting. For example, "Alignment with learning outcomes" is weighted at 25%, contributing a maximum of 25 points to the overall score of 100 points.

<i>Criteria</i>	<i>Inadequate (0 - 49%)</i>	<i>Good (50 - 69%)</i>	<i>Excellent (70 - 79%)</i>	<i>Outstanding (80 - 100%)</i>
<i>Alignment with learning outcomes (25%)</i>	<i>1 – 12 pts</i> Criteria are poorly aligned or unrelated to learning outcomes.	<i>13 – 15 pts</i> Criteria are marginally aligned but may be overly general or inconsistent.	<i>16 – 17 pts</i> Mostly aligned with learning outcomes; minor disconnects in criteria.	<i>18 – 25 pts</i> Clearly and directly aligned with developmental learning outcomes; each criterion reflects targeted skills & competencies.
<i>Clarity and specificity of language (20%)</i>	<i>0 – 9 pts</i> Descriptors are unclear, inconsistent, or overly specific.	<i>10 – 13 pts</i> Language is sometimes vague or inconsistent; may confuse learners.	<i>14 – 15 pts</i> Mostly clear language; some descriptors could be refined.	<i>16 – 20 pts</i> Language is precise, learner-friendly, and clear across all levels.
<i>Progression of skill development (25%)</i>	<i>1 – 12 pts</i> No clear progression; levels appear arbitrary or repetitive.	<i>13 – 15 pts</i> Developmental progression is weak or uneven.	<i>16 – 17 pts</i> Levels reflect development, but the descriptors distinguishing one level from the next are too similar.	<i>18 – 25 pts</i> Levels represent a meaningful and realistic developmental progression of skill mastery.

<i>Criteria</i>	<i>Inadequate (0 - 49%)</i>	<i>Good (50 - 69%)</i>	<i>Excellent (70 - 79%)</i>	<i>Outstanding (80 - 100%)</i>
<i>Usefulness for intended purpose (15%)</i>	<i>0 – 7 pts</i> Provides little or no value for grading or giving specific feedback depending on the intended use.	<i>8 – 10 pts</i> Allows for general feedback but limits the ability of specific feedback.	<i>11 pts</i> Some support for specific feedback but does not enable students to reflect on their own work.	<i>12 – 15 pts</i> Encourages self-assessment, goal-setting, and constructive feedback.
<i>Usability and practicality (15%)</i>	<i>0 – 7 pts</i> Unwieldy or confusing to apply; inconsistent scoring likely.	<i>8 – 10 pts</i> Some usability concerns; rubric may be difficult to implement.	<i>11 pts</i> Rubric functions well; minor issues with consistency or application.	<i>12 – 15 pts</i> Easy to apply reliably; promotes consistency across evaluators; adaptable.

Unlike the holistic rubric shown in Table 3.4.6, which provides a single overall judgement of teamworking performance based on a broad description of performance, the rubric in Table 3.4.8 evaluates multiple dimensions of teamworking separately. Each criterion is assigned the same numerical weight and is scored on a four-point scale from 1 (Unsatisfactory) to 4 (Exemplary). The scores awarded for each criterion are then summed to produce a total score.

When used formatively, the primary purpose of this rubric is to provide detailed feedback on specific aspects of teamworking, helping students identify strengths and areas for improvement. If used summatively, the total score must be mapped to grade boundaries or performance categories established by the module team or institution. For example, a rubric containing five criteria would generate a total score ranging from 5 to 20 points, which could then be translated into pass, merit, or distinction classifications. The specific thresholds should be determined during rubric design and communicated clearly to students before the assessment.

Table 3.4.8: Example of an analytic rubric to assess working in a team, using criteria that have the same numerical weight (from Rogers 2010)

	<i>Unsatisfactory 1 pt</i>	<i>Developing 2 pts</i>	<i>Satisfactory 3 pts</i>	<i>Exemplary 4 pts</i>
<i>Research & gather information</i>	Does not collect any information that relates to the topic.	Collects very little information; some relates to the topic.	Collects some basic information; most relates to the topic.	Collects a great deal of information; all relates to the topic.
<i>Fulfil team role duties</i>	Does not perform any duties of assigned team role.	Performs very little duties.	Performs nearly all duties.	Performs all duties of assigned team role.
<i>Share in work of team</i>	Always relies on others to do the work.	Rarely does the assigned work; often needs reminding.	Usually does the assigned work; rarely needs reminding.	Always does the assigned work without having to be reminded.
<i>Listen to other teammates</i>	Is always talking; never allows anyone else to speak	Usually doing most of the talking; rarely allows others to speak.	Listens, but sometimes talks too much.	Listens and speaks a fair amount.

Table 3.4.9: Sample rubrics designed for analysis of an accrediting body criteria for a project design module, using criteria that have the same numerical weight (from Mahajan & Bansal, 2023)

	<i>Unsatisfactory 1 pt</i>	<i>Developing 2 pts</i>	<i>Satisfactory 3 pts</i>	<i>Exemplary 4 pts</i>
<i>Ability to identify a real life/societal problem to be addressed, using engineering skills and define objectives.</i>	Unable to identify problem statement.	Able to identify problem statement but not able to define clear objectives.	Problem statement is identified but objectives are only partially defined.	Problem statement is identified/defined in a precise manner; objectives are complete and well-defined.

	<i>Unsatisfactory 1 pt</i>	<i>Developing 2 pts</i>	<i>Satisfactory 3 pts</i>	<i>Exemplary 4 pts</i>
<i>Ability to produce and enlist a wide set of problem-specific design solutions along with project-specific schedule and budget to meet functional requirement of societal and environmental needs.</i>	Unable to produce any possible solution to defined problem. Unable to develop neither schedule nor budget.	Only one possible solution is presented. Technicalities are not clear. Able to develop either schedule or budget.	Alternative solutions are presented but not able to pick optimal design solution with required justification. Developed both schedule and budget but these are unrealistic.	Capable of generating and comparing solutions to identify the optimal design. Able to define hardware and software requirements through systematic literature review. Detailed and realistic schedule and budget are developed.
<i>Ability to create a prototype to solve a real-life problem.</i>	Unable to identify process tools to develop prototype.	Develops a prototype but does not cater to solve real life problems.	Prototype solves 70% of real-life problem.	The developed prototype is capable to solve real-life problem.
<i>Ability to systematically evaluate designs to meet societal and environmental needs.</i>	No prototype development and validation are done.	Prototype is developed but unable to validate it against real-life problems.	Partial validation is done.	Complete module integration, verification, and validation of prototype.

6 Concluding remarks

Assessment rubrics are invaluable tools that bridge the gap between teaching, learning, and evaluation by clearly defining expectations and standards of quality. As explored in this chapter, the development and implementation of effective rubrics require careful consideration of their purpose, design, and impact on both assessees and assessors. Whether used formatively to guide and support student progress or summatively to assign grades, rubrics must be thoughtfully aligned with learning outcomes and constructed to promote fairness, transparency, and consistency.

Holistic and analytic rubrics each offer distinct advantages and challenges, and the choice between them should be informed by the nature of the task, the skills being assessed, and the type of feedback desired. Critical to the success of any rubric is clarity — clear, measurable criteria paired with detailed performance descriptors that articulate expectations at varying levels of achievement. Moreover, involving multiple stakeholders, particularly assessors and assessees, in the rubric development and calibration processes enhances reliability and fosters shared understanding.

Best practices in rubric development emphasise a systematic approach: defining purpose, aligning criteria with learning outcomes, articulating performance standards, and iteratively refining the tool through feedback and trialling. Effective rubrics not only facilitate reliable assessment but also contribute significantly to student learning by providing actionable feedback and encouraging self-reflection.

Ultimately, rubrics serve as a form of educational contract that guides both teaching and learning. When designed and applied thoughtfully, they promote equity, support skill development, and uphold academic standards, thus making them essential instruments in educational practice.

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AI statement

During the preparation of this work, the authors used ChatGPT in order to ideate Tables 3.4.5 and 3.4.7. After using this tool, the authors reviewed, edited and made the content their own as needed. They take full responsibility for the content of the publication.

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3.5

Observations and the Assessment of Behaviours

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Observations involve the deliberate, systematic, and purposeful act of watching and listening to learners as they engage in tasks relevant to their work, enabling educators to assess and provide feedback on learners' competencies and to track how these competencies develop over time. This chapter is written for engineering educators and assessors who wish to incorporate observational assessment into their practice, with particular emphasis on non-technical skills. It explores how behaviours are observed within educational settings, with particular attention to Behavioural Marker Systems (BMS) as structured observational frameworks for competencies such as communication, teamwork, leadership, transferable competencies and skills, and problem solving. The chapter guides readers through principles, methods, and pragmatic steps for planning and conducting observations of non-technical skills, and for establishing and validating a BMS for engineering contexts.

1 Introduction

Engineering education is fundamentally a social process. It unfolds through a series of sociotechnical interactions, where learners engage with instructors, peers, learning materials, and their environment. These interactions vary in their degree of planning and purpose, and as an educator, you have likely experienced how profoundly they are shaped by learners' behaviours.

You invest significant effort in creating constructive environments to support learning. But have you also built the right infrastructure to observe your learners within these settings? From the front of a lecture theatre, you might see students scribbling notes, yawning, or chatting with peers. But how can you tell if they are learning?

Observations involve the deliberate, systematic, and purposeful act of watching and listening to learners as they engage in tasks relevant to their work. Despite their value, observations are often overlooked by educators, who may feel uncertain about how to select appropriate observational frameworks or implement them effectively in their own context. The purpose of this chapter is to demystify observational assessment and provide practical guidance on how to embed it into your teaching practice.

In this chapter, we help you formalise the way you plan and conduct observations of learning, particularly in the context of assessing competencies. We remain flexible in our approach, highlighting guiding principles for good practice and grounding these techniques in educational research. Specifically, we begin in Section 2 by defining observational methods and outlining the hierarchy of approaches available to educators. Section 3 explores how to establish robust observational frameworks, drawing on research methodologies while acknowledging their limitations and nuances. We turn to a practical case study of a Behavioural Marker System (hereafter, BMS) in development from our research at King's College London, before broadening our discussion to offer general recommendations for implementing good practice. While much of the BMS literature originates from industry contexts (and indeed, you will notice that we have drawn from several industrial examples in our references), we believe their principles apply equally well to educational settings and will help you understand how an engineering observational framework was created within a Higher Education context.

This chapter is written for engineering educators and assessors who are seeking to incorporate observational assessment into their programmes, whether in project-based modules, laboratories, design studios, or workplace learning. Observational assessment is particularly valuable for competencies highlighted in the SEFI handbook and the Engineering Education Research (EER) taxonomy, such as communication, teamwork, leadership, and professional skills, because these outcomes are enacted through observable behaviour in context rather than solely through written products or tests. For problem solving, for instance, observation allows assessors to see how students define problems, seek information, and respond to uncertainty during authentic tasks, complementing product-focused assessments.

2 Definition of observational assessment

Observational assessment is widely recognised as a fundamental method for evaluating human performance, particularly in high-stakes, high-reliability domains such as aviation and healthcare (Flin, O'Connor & Chrichton, 2017). It offers a structured approach to observe, record, interpret, and evaluate an individual's or team's actions against predefined standards. In this chapter, we interpret behaviour as the way individuals enact a competency through their skills, attitudes, and knowledge. In Chapter 1.2 of the handbook, competencies and their many definitions have been discussed at length. One such definition states that while competencies are understood to encompass knowledge, skills, and attitudes (Crichton et al., 2017), attitudes and knowledge are internal states that cannot be directly observed. Observation provides the critical link between these internal competencies and the external behaviours that demonstrate them. Behavioural assessment therefore aims to infer these internal competencies from external cues — what individuals say, do, or omit — while performing a task.

By systematically studying human interactions with tasks, equipment, systems, and one another, observation captures evidence of competency in action during training, licensing, and ongoing professional development. This process typically involves watching individuals or teams as they perform tasks in either real-world or simulated environments, enabling the collection of rich data on behaviours, decision making, and collaboration. Observational methods can be qualitative or quantitative, self-directed or externally conducted, depending on the purpose and level of detail required (Flin et al., 2017).

Building on this premise, we will guide you through how we have worked on Behavioural Marker Systems, as they offer structured taxonomies of skills, elements, and associated behaviours for training and assessment (Flin et al., 2006). They are grounded in the idea that observable behaviours provide evidence of underlying skills and knowledge (Tefera, 2019) and are thus particularly interesting for practitioners who want to understand the formalisms of observational assessment science.

A BMS is a structured framework comprising categories of non-technical skills, their behavioural elements, and associated poor and good performance indicators, designed to support systematic observation, assessment, and formative feedback in authentic tasks (Hamlet et al., 2023).

BMS are introduced here as a case study because they exemplify how observational assessment can be systematically designed to capture complex competencies, bridge the gap between observable actions and underlying skills, and provide actionable insights for both training and performance evaluation. Their structured approach allows for practical demonstration of the principles discussed in this chapter, making abstract concepts of competency assessment tangible and operational. Before introducing how to work with BMS further (Section 3), let us discuss the context and limitations of observational assessments at a general level.

2.1 Using observations for assessment

The observation of behaviour as evidence of competency can be approached using different techniques. At one end of the spectrum are structured methods, such as predefined checklists designed to help observers identify specific cues. At the other end are open-ended approaches, where observers record free-text notes based on their observations. A mixed approach can also be employed, combining the strengths of both methods. Common data collection techniques include anecdotal records, rating scales, checklists, event and time sampling, as well as the use of live, recorded, or instrumented (technology-enabled) observations. The role of the observer may also vary, ranging from participatory, where the observer is involved in the activity being studied, to external, where they remain detached from the process.

Specialised observation formats have been developed to enable the systematic use of behaviours for assessment and feedback. One such approach is the use of behavioural marker systems, structured observational tools originating in medical and emergency training contexts. Behavioural marker systems provide structured frameworks for observing and rating specific actions or behaviours. By organizing these behaviours into skill categories, elements, and observable performance indicators, they support consistent training, assessment, and feedback (Fletcher et al., 2003).

Beyond BMS, several other approaches exist for assessing and developing competencies. Assessment centres, for example, are structured processes in which individuals complete multiple tasks, such as role-plays, group discussions, and interviews, designed to evaluate specific competencies. Trained assessors observe and score behaviours to provide a reliable and well-rounded picture of an individual's suitability for a job, promotion, or development opportunity (Ballantyne & Povah, 2017). Development centres share many similarities with assessment centres but focus more explicitly on individual growth and learning rather than selection or recruitment. Through exercises such as role-plays, feedback sessions, and psychometric tests, these centres help identify strengths and areas for development, offering participants targeted support for improvement.

Finally, the increasing use of digital technologies has enabled the emergence of instrumented teamwork approaches, such as those explored in the MIT System Design & Management programme (Graham 2022). Here, digital tools and data collection systems are employed to monitor, support, and assess collaborative learning activities. By capturing interactions such as communication patterns, task contributions, and coordination efforts, these tools provide students and educators with feedback that can be used to improve teamwork processes and enable evidence-based evaluation.

Table 3.5:1: Commonly used observational methods discussed in this section, with indicative uses and limitations in engineering education

<i>Method</i>	<i>Description</i>	<i>Suggested use in engineering education</i>	<i>Limitations</i>
<i>Structured checklists</i>	Predefined behaviours list; tick-off during observation (Flin et al., 2017)	Safety monitoring in labs; coverage in design-build-test tasks (Flin et al., 2017)	Superficial box-ticking risk; misses quality and context adaptation (Flin et al., 2017)
<i>Open-ended field notes</i>	Free-text behaviour descriptions; written during or after observation	Early BMS development; piloting project-based modules	Time-consuming to analyse; inconsistent across observers
<i>Rating scales</i>	Numerical/descriptive scales; anchored with performance descriptors (Hamlet et al., 2023)	Teamwork, communication, leadership; group projects and design reviews	Needs clear anchors and rater training; reliability needs calibration (Hamlet et al., 2023)
<i>Anecdotal records</i>	Brief, specific incident accounts; illustrates key competencies	Conflict management moments; ethical decision points in projects	Underrepresents routine positives; subject to selective recall
<i>Event or time sampling</i>	Records at set time intervals or when specific events occur	Tracking feedback-seeking frequency; peer involvement in lab sessions (Flin et al., 2017)	Increases observer workload; may miss infrequent behaviours
<i>Video-based observation</i>	Recorded/live-capture scenarios; supports repeated reflective review (Hamlet et al., 2023)	Simulation debriefings; capstone reviews and assessor calibration	Camera/audio may obscure cues; over-focus on visible behaviours
<i>Behavioural Marker Systems (BMS)</i>	Taxonomy of non-technical skills; behavioural elements and rating scales (Hamlet et al., 2023; Tefera, 2019)	Communication, teamwork, ethics; design projects, labs, simulations	High development effort; high cognitive load for new assessors

2.2 Observability and its limitations

Observational assessment is a powerful tool for evaluating human performance, but it has recognised limitations. A central challenge is the invisibility of covert cognitive processes: decision making, planning, and other internal mental activities are not directly observable. While these processes can sometimes be inferred from communication or external actions, they remain largely hidden to observers (Thompson, 2013).

Furthermore, the capabilities of human observers impose practical constraints. Observers can experience cognitive overload, fatigue, distraction, or unconscious bias, particularly in high-pressure or complex environments (O'Connor et al., 2002; Thompson, 2013). These factors can compromise the accuracy, consistency, and fairness of assessments. Subtle or infrequent behaviours can be missed altogether, while very frequent behaviours may need capping to prevent excessive recording and maintain focus. Detecting omissions, i.e., the absence of expected action, requires especially skilled observers familiar with the task. As Thompson (2013, p. 113) notes: *"Through focusing specifically on the recording of overt explicit behaviour, the method precludes the direct recording of omissions... The detection of omitted behaviour lends itself more to scripted test environments where the occurrence (or not) may be anticipated by the observer."*

These challenges are further amplified in virtual environments. Physical, cognitive, and psychological 'virtualisation' can reduce social presence, obscure non-verbal cues, and fragment attention, making it harder to interpret collaborative dynamics or engagement authentically. Observers must adapt frameworks and expectations to ensure fair and meaningful assessments in these contexts.

An important design principle in observational assessment is the focus on behavioural patterns rather than personality traits or attitudes. Behavioural marker systems (BMS) and similar tools should describe specific, observable behaviours that reflect skills or knowledge in action, not subjective traits (Klampfer et al., 2001). While personality influences behaviour, assessment and training interventions target modifiable behavioural patterns that impact performance rather than attempting to change inherent personality characteristics (Flin et al., 2017). As Flin et al. (2017, p. 9) note: *"The interventions... are about changing patterns of behaviour rather than attempting to modify the individual's underlying personality."*

For example, an autocratic leader may need to adopt behaviours that encourage team input, while introverts may need to practise outward communication, and extroverts may need to focus on active listening (Flin et al., 2017). Distinguishing between personality and behaviour ensures objectivity and keeps assessments development-oriented rather than judgemental.

The validity and reliability of observational assessments depend heavily on how observations are structured and interpreted. Bias can emerge through halo effects, confirmation bias, or cultural and gender stereotypes, especially in unstructured settings or peer assessments. Structured rubrics, observer training, multiple assessors,

and reflective practices help mitigate these risks, particularly in complex domains like teamwork and professionalism (O'Connor & Long, 2011).

The modality of observation also shapes what cues are available. In-person observations capture full non-verbal communication, including body language and eye contact, while video may omit peripheral or spatial cues. Audio-only modalities, in turn, rely entirely on tone, pace, and language, excluding visual signals. Because non-verbal cues are context-dependent and culturally variable, observers must consider task context, relationships, and cultural norms to avoid misinterpretation.

To enhance validity and insight, educators can employ observational lenses, i.e., structured perspectives for analysing practice. Aligned with Brookfield's (1995) four lenses of feedback — autobiographical, student, colleague, and theoretical — these lenses help educators interpret complex interactions from multiple viewpoints, making observations more focused, actionable, and reflective.

Observational frameworks are most powerful for formative assessment, feedback, and professional development, where the goal is reflection and improvement rather than high-stakes judgement. Their structured nature promotes transparency, alignment with learning outcomes, and consistency across multiple assessors. However, the subjectivity of observation and the influence of bias and context mean that for summative assessment, robust safeguards, such as clear criteria, rater training, and moderation, are essential to ensure reliability. With these safeguards, observational frameworks can meaningfully contribute to both formative and summative assessment, especially for complex competencies such as teamwork, communication, and professionalism.

Observations can be longitudinal, capturing behavioural patterns and growth over time, offering insights into development and consistency but requiring sustained effort and observer continuity. They can also be event-based, focusing on specific moments like presentations or simulations, offering efficiency and detail but risking misrepresentation if the event is uncharacteristic. Both approaches are complementary, and their integration provides a fuller understanding of performance.

Finally, observational assessments may target individual performance, team performance, or both. For instance, systems like "*Non-Technical Skills*" (NOTECHS) assess individual pilots (Flin et al., 2003), while the Anaesthetist's Non-Technical Skills (ANTS) focuses on individual anaesthetists (Fletcher et al., 2004). In contrast, many BMS frameworks, such as those developed for drilling teams (Crichton et al., 2017) or search-and-rescue crews (Hamlet et al., 2023), emphasise collective competencies such as coordination, communication, and adaptability, which are essential for achieving shared goals.

3 GENTS-BMS: steps towards developing an observational framework

Behavioural Marker Systems are well established in professional and safety-critical education, including healthcare, aviation, emergency services, and other domains

where non-technical skills are learned through practice. Their use in engineering higher education is much less developed. In this section, we will consider the example of the *General Engineering Non-Technical Skills Behavioural Marker System (GENTS-BMS)* that we developed during PhD research at King's College London between 2022 and 2026 to implement in the General Engineering undergraduate programme of our engineering department. We hope this demonstrates the different ways in which you can establish and validate an observational framework and can support your development of a research-informed framework to use in teaching.

The example therefore does not claim to provide a fully validated engineering education instrument for you to readily use in your teaching, albeit you can find example implementations in the reference videos of Lucas & Ciriello (2026). Instead, it illustrates how an engineering educator might translate BMS principles into a usable observational framework for project-based, laboratory, studio, or simulation-based engineering learning.

3.1 Context of the case study

Our *GENTS-BMS* was developed through an iterative process that combined literature, expert knowledge, and practitioner feedback (Lucas & Ciriello, 2026). We started by reviewing non-technical skills to form an initial set of categories and elements, which we then presented in semi-structured interviews to senior engineers and engineering leaders across the UK to elicit concrete behavioural examples of good and poor performance, each mapped onto skill categories. We also ran validation workshops at engineering education conferences (EERN, SEFI), which involved educators sorting and critiquing behavioural elements, refining wording, and checking recognisability and distinctiveness of categories. Curriculum integration is still ongoing, and further work is underway to evaluate its application in educational settings, refine the behavioural markers based on implementation feedback, and establish how the framework can best support the development and assessment of non-technical skills in engineering students.

3.2 Methodologies to establish a Behavioural Marker System

Establishing a BMS is a rigorous process that typically involves several integrated methodologies to ensure the system is comprehensive, context-specific, and accurately reflects real-world performance (Hamlet et al., 2023). As an educator, you will be confronted with several choices for how to establish your observational framework, and indeed you should seek to draw from good practices across a range of steps, particularly in how you draw behaviours from literature, events, tasks, interviews, focus groups or direct observation.

The aim for a BMS is to define observable, non-technical behaviours that contribute to superior or substandard performance within a specific work environment (Dias et al., 2023), and there are many ways to approach these definitions.

Literature review

As an initial step, you will survey existing scientific literature to identify established non-technical skills taxonomies and behavioural marker systems developed in similar or related domains. This helps in establishing a baseline understanding of common categories and elements of behaviour already recognised in the field (Yule et al., 2006).

To establish our GENTS-BMS skills taxonomy, we conducted a systematic literature review of non-technical skills literature in engineering education, and used frequency of mentions to establish skills categories and elements (Jaberi, Ciriello & Lucas, 2024). When approaching the literature review, you will quickly notice that the field lacks conceptual clarity and you might be rightfully be worried that any meaningful assessment is only possible when concepts are clearly defined. For example, 53% of papers we reviewed did not explicitly define the soft skills they investigated.

The process of building a taxonomy is therefore as much about clarifying concepts and boundaries as it is about identifying skills. A useful taxonomy distinguishes between underlying dispositions and observable behaviours, is grounded in disciplinary context, and is designed from the outset to support assessment and development. The move from broad skill labels to observable behaviours is where a taxonomy becomes usable.

Event-based analysis (incidents and accidents reports analysis)

In a high-stake environment, event-based analysis, specifically the examination of incidents and accident reports, constitutes a methodologically rigorous approach for identifying behavioural patterns that either contribute to, or mitigate against, adverse outcomes, human error, and safety-related events (O'Connor & Long, 2011, Tefera, 2019). This approach entails the systematic collection of documented analyses from organisations, alongside incident data and formal reports (Thompson, 2013).

Within these reports, human factors are scrutinised with a focus on isolating procedural lapses, errors, or deviations that can be attributed to identifiable behavioural antecedents. The analytic process further involves the extraction of particular instances in which non-technical skills such as communication, decision making, or situational awareness either exacerbated the incident or facilitated its mitigation (Hamlet et al. 2023).

We think it is worth acknowledging that this is often the ideal method, but one that is not always feasible, particularly outside high-risk industries where access to incident data may be restricted or where formal reporting systems are less mature (indeed we did not use this event-based analysis in GENT-BMS). Access to incident reports is often restricted due to confidentiality, and the systematic coding and analysis of large numbers of reports requires considerable time and expertise. Practitioners developing a BMS may therefore adopt a more pragmatic approach by reviewing publicly available accident investigation reports, published case studies, regulatory safety bulletins, or organisational lessons-learned documents. Although these sources may not provide the same breadth or contextual richness as internal incident databases, they can still

yield valuable insights into the behaviours associated with successful and unsuccessful performance and help validate or refine an emerging taxonomy.

Cognitive Task Analysis (CTA)

One of the most effective ways to develop behavioural markers is to talk directly to experienced practitioners. Many aspects of non-technical performance are tacit: experts recognise good communication, sound judgement or effective leadership when they see it, but rarely describe these behaviours explicitly. Cognitive Task Analysis (CTA) provides a structured way of making this expertise visible by encouraging experts to reflect on how they think, make decisions and behave in real situations (Yule et al., 2006).

Rather than asking experts to describe what makes a 'good engineer', ask them to recall specific incidents they have experienced. While confidentiality constraints may prevent practitioners from sharing details of specific workplace incidents, they are often able to discuss these experiences in more general terms by describing representative or idealised scenarios. Semi-structured interviews, combined with the Critical Incident Technique (CIT), are particularly well suited to this purpose because they encourage discussion of real examples rather than abstract opinions. Ask participants to describe both successful and unsuccessful situations, then probe how they recognised the problem, what information they considered, what actions they took, why they chose those actions, and how the outcome might have been different. This approach helps uncover the behaviours that distinguish stronger and weaker performance (Hamlet et al., 2023).

In developing GENTS-BMS, we interviewed experienced engineers and engineering educators from industry, higher education, recruitment, and professional accreditation, ensuring that each non-technical skill domain was discussed by individuals with substantial expertise. Rather than beginning with a blank sheet of paper, interviews were structured around the emerging non-technical skills taxonomy developed through the literature review and expert workshops. Each participant was first asked to describe the characteristics of a high-performing engineer before discussing one specific non-technical skill category in depth. For every skill element, participants were invited to describe how high-performing and lower-performing engineers behave in practice, allowing positive and negative behavioural markers to be elicited in parallel.

A key lesson from this work was the importance of continually redirecting participants towards observable behaviour. Experts naturally tend to describe attributes such as 'good communicator' or 'strong leader'. Your role as interviewer is to probe further: What did they actually do? What questions did they ask? What did they say in the meeting? What would I have observed if I had been standing next to them? These follow-up questions transform abstract competencies into behavioural markers that can later be observed and assessed. This behaviour-focused questioning was central to the development of GENTS-BMS and is consistent with knowledge elicitation

approaches used in behavioural marker systems developed for aviation and healthcare.

Finally, record and transcribe the interviews before systematically coding the data against your developing taxonomy. We recommend distinguishing examples of effective and ineffective performance within each skill element, then rewriting these as short, observable behavioural statements. Avoid statements that describe personality or internal thought processes; instead, write markers that describe actions someone could realistically observe during a project, laboratory session or design review. These behavioural statements become the foundation of your behavioural marker system.

Focus groups

Once you have developed an initial set of non-technical skill categories and behavioural markers, the next step is to test them with a wider group of experts. Focus groups and facilitated workshops provide an opportunity to validate your emerging framework, challenge assumptions, and build consensus about whether the behaviours accurately reflect effective professional practice (Butler et al., 2020).

Rather than presenting participants with a blank sheet of paper, provide them with the draft taxonomy and behavioural markers generated through your literature review, interviews, and other evidence sources. This gives the discussion a clear focus and allows participants to concentrate on refining the framework rather than creating it from scratch. Encourage participants to question whether each behavioural marker is clear, observable, and representative of the skill it is intended to describe. Ask whether important behaviours are missing, whether some markers overlap, or whether behaviours would be better assigned to another skill category (Hamlet et al., 2023; Irwin et al., 2023).

In developing GENTS-BMS, we used workshops with engineering educators, industrial partners, professional body representatives, and other engineering stakeholders to iteratively refine the framework. Participants worked through each non-technical skill category, discussing the proposed behavioural markers and suggesting additions, modifications, and rewording where appropriate. These discussions also helped identify behaviours that appeared under multiple skills, allowing the framework to be simplified and improving the distinction between categories. Repeated review across multiple workshops gradually strengthened both the content and organisation of the behavioural marker system.

A key advantage of group discussion is that it exposes differences in perspective. Industry practitioners, educators, employers, and professional bodies often emphasise different aspects of engineering practice. Rather than viewing these differences as disagreement, treat them as an opportunity to develop behavioural markers that are applicable across a range of engineering contexts. Where consensus cannot immediately be reached, record the differing viewpoints and revisit them during subsequent iterations rather than forcing agreement during the workshop.

As the discussion progresses, continually return participants to observable behaviours. Experts frequently propose statements such as 'demonstrates professionalism' or 'shows leadership'. Encourage them to explain how this would be observed in practice. Ask questions such as: How would you recognise this behaviour? What would you expect to see or hear? What would distinguish excellent from poor performance? These prompts help transform broad competencies into behavioural markers that can be observed consistently by different assessors.

Finally, document all proposed changes and revise the framework after each workshop. It is often more effective to undertake several rounds of focused review with smaller groups than to attempt to produce a final framework in a single session. An iterative process of discussion, revision, and revalidation helps ensure that your behavioural marker system is comprehensive, coherent, and supported by the wider engineering community (Butler et al., 2020; Hamlet et al., 2023).

Direct observation

While interviews and focus groups provide valuable insights into how experts understand non-technical skills, direct observation allows you to examine how these skills are demonstrated in practice. By observing individuals while they perform authentic tasks, you can identify whether the behaviours described in your emerging framework are visible, meaningful, and relevant in real contexts (Thompson, 2013).

Direct observation is particularly valuable because non-technical skills are often difficult for individuals to articulate. An engineer may recognise effective teamwork, decision making, or situational awareness without being able to explicitly describe the behaviours that demonstrate these skills. Observing performance allows you to capture these behaviours as they occur, reducing reliance on memory and self-reporting. Depending on your context, observations may be conducted during workplace activities, design reviews, laboratory sessions, project meetings, simulations, or other authentic learning activities.

When conducting observations, focus on recording what people do, rather than interpreting their intentions. For example, instead of noting that a student 'demonstrated good communication', capture the specific behaviours that led to this judgement: asked clarifying questions before starting a task, shared relevant information with team members, or adapted their explanation when others showed uncertainty. Similarly, documenting ineffective behaviours is important, as these provide useful contrasts and help define the boundaries of acceptable performance.

In developing a behavioural marker system, direct observation can serve two purposes. First, it can validate whether the behavioural markers identified through literature reviews, interviews, and focus groups are observable in practice. Second, it can reveal new behaviours that were not captured through earlier methods. For example, observing engineers or students working through complex design challenges may highlight subtle behaviours related to collaboration, problem framing, or decision making that experts did not initially articulate (Thompson, 2013). However, direct observation can be challenging to implement. It requires access to appropriate

activities, sufficient time for observation, and observers who understand both the technical context and the purpose of the behavioural marker system. In educational settings, you may not be able to observe every student or every activity in depth. A pragmatic approach is therefore to begin with a smaller number of representative observations, using these to test and refine your behavioural markers before scaling up.

A useful approach is to combine observation with the other methods described in this chapter. A literature review can provide the initial structure of your taxonomy; interviews and focus groups can reveal expert knowledge and contextualise behaviours; and direct observation can confirm that these behaviours occur in practice. Using multiple sources of evidence helps ensure that your behavioural marker system is not only theoretically grounded but also reflects the realities of professional practice (Butler et al., 2020).

Validating Behavioural Marker Systems

Once an observational assessment such as a BMS has been developed, it is important to evaluate whether it is reliable, valid, and suitable for its intended purpose. Validation helps to establish confidence that the system provides meaningful and consistent information about non-technical skills, rather than simply reflecting individual assessor interpretation or contextual factors.

Reliability refers to the consistency of assessment results across observers and occasions. In behavioural marker systems, inter-rater reliability is particularly important because it indicates whether different assessors observing the same behaviour apply the rating criteria in a comparable way. A reliable system therefore promotes shared interpretation of performance and limits the extent to which assessment outcomes depend on individual assessor judgement (Fletcher et al., 2003). Test-retest reliability considers whether the system produces consistent results when the same individuals are assessed on different occasions, while internal consistency examines whether the behavioural markers within a particular skill category work together to represent a coherent aspect of performance (Ravindran et al., 2021; Flowerdew et al., 2012).

Validity considers whether the BMS is measuring what it is intended to measure. Content validity is established by ensuring that the framework adequately represents the relevant non-technical skills for the target context, typically through expert review and consultation (Tefera, 2019). Face validity considers whether practitioners recognise the behaviours as meaningful and appropriate, which is important for gaining acceptance and encouraging engagement with the system (Butler et al., 2020). More formal evaluations of construct validity examine whether the BMS captures the underlying skills it aims to assess, while criterion or predictive validity explores whether BMS ratings relate to relevant indicators of performance, such as project outcomes or operational success (Tefera, 2019; Nixon et al., 2015).

For educators implementing a BMS, validation does not need to begin with complex statistical analysis. Practical evaluation methods, such as gathering feedback from

assessors and students, reviewing examples of assessed behaviours, and discussing whether ratings align with observed performance, provide valuable evidence for improving the system. Usability and acceptability are particularly important: a BMS must be understandable, manageable to apply, and perceived as useful by those using it (Butler et al., 2020; Thompson, 2013). Finally, consider whether the system is sufficiently sensitive to distinguish between different levels of performance. This is essential if the BMS is intended not only for assessment, but also to support formative feedback and the development of students' non-technical skills (Tefera, 2019).

4 Recommendations for implementation

The successful implementation of observational assessment systems relies on several best practices designed to ensure accuracy, consistency, and meaningful impact. First, rater training is essential for maintaining reliability and fairness. Training should combine theoretical understanding with practical application and calibration exercises so that observers develop a shared interpretation of behaviours and performance standards (Dietz et al., 2014).

The use of video recordings offers additional benefits, enabling repeated viewing for detailed analysis and supporting rater calibration by allowing all observers to assess the same performance. Video also provides concrete examples for feedback and training sessions, helping to ground discussions in observable evidence (Thompson, 2013).

Providing clear feedback and structured debriefing to students is another critical element. Observational systems should support constructive dialogue by linking performance scores to explicit behavioural examples. Debriefing should focus on the implications of behaviours for performance rather than on numerical ratings alone, fostering learning and reflection (Rasmussen et al., 2019; Yule et al., 2008).

A multi-method approach strengthens the validity of findings by combining observational data with complementary sources such as interviews, surveys, or incident analyses. This triangulation provides a more comprehensive picture of performance and its influencing factors (Flin et al., 2017).

Furthermore, iterative development and validation are vital. Your observational framework should evolve over time through systematic testing of reliability, validity, sensitivity, and usability. Long-term validation studies, such as those undertaken to develop BMS in aviation and healthcare, highlight the importance of refining these systems to ensure they accurately differentiate between performance levels (Fletcher et al., 2003, Hamlet et al., 2023).

Finally, organisational support underpins successful implementation. Integrating observational assessment into existing processes requires commitment from leadership as well as buy-in from students and educators (Flin et al., 2017). For an observational framework to become embedded in practice, leadership must recognise non-technical skills as an important component of engineering education and provide the time, resources, and training required for consistent use (which as you have seen

from the GENTS-BMS case study, are considerable). This includes supporting educators in interpreting and applying behavioural markers, aligning the assessment approach with existing curriculum and quality processes, and communicating to students that the purpose of the observations is developmental rather than simply evaluative.

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3.6

A Transferable Competency Portfolio Based on the Personal Development Process

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In education, a portfolio is a compilation of learning experiences that highlights a student's individual learning trajectory. As an assessment method, portfolios can emphasise the learning process and support the development of self-regulation. This chapter presents a developmental portfolio used in a project-based learning module for engineering students. Through its content, the portfolio supports the development of transferable competencies, while its structured process fosters self-regulation and other lifelong learning competencies, thus preparing students for lifelong learning. Results from different campuses and across bachelor years are presented, showing how students' portfolio outcomes developed over time, as well as how feedback practices influenced student engagement. Drawing on these findings and our experiences, we propose practical recommendations for educators, including strategies to incorporate the portfolio throughout the curriculum and to create clear expectations around feedback. In doing so, this chapter aims to inspire educators to adopt or adapt portfolio practices in ways that strengthen lifelong learning competency development in engineering education.

1 Introduction

A portfolio in the formal higher education context is a compilation of learning experiences and activities that highlights an individual's learning trajectory within this context (Alam et al., 2015; Chaudhuri & Cabau, 2017; Dujardin et al., 2024). Different types of portfolios exist, but some key features of portfolios as assessment methods are that they emphasize the individual learning process, increase the responsibility of students in their learning activities and learning process, and are used as a condensed version of learning that can be used for communication with educators and potential employees. Given these characteristics, portfolios align closely with the aims of Part 3 of this handbook, which showcases evidence-based examples of assessing competency development in engineering education.

This chapter presents an example of such a portfolio, aiming to inspire educators to either implement a portfolio or adapt an existing one to place greater emphasis on lifelong learning competencies or other competencies. First, the use of portfolios in higher education and specifically in engineering is described with special attention to the different types of portfolios (Section 2.1). This is followed by an illustration of how the lifelong learning competencies in this handbook are part of this portfolio. Next, our implementation of a portfolio is discussed, which is a portfolio focusing on transferable skills in a project-based learning module. Based on our use of this assessment method, we propose practical recommendations for implementation.

2 The use of portfolios

2.1 *Different types of portfolios in higher education*

Portfolios have long been established as a widely used educational tool in higher education, applied across a broad range of disciplines and contexts. Portfolios are used in higher education with different objectives. Alam et al. (2015) described four types of portfolios:

1. *Developmental portfolios* focus on the learning process, supporting students' ongoing growth through self-assessment, feedback, and reflection. The emphasis is on progress and skill development over time rather than the final product.
2. *Showcase portfolios* highlight the learning product, collecting evidence of achievement or mastery of competencies. These are often used to demonstrate skills to educators or potential employers, emphasizing the quality and completeness of the work.
3. *Assessment portfolios* are intended for formal evaluation, documenting student mastery of competencies against predefined standards or learning outcomes. The focus is on measuring performance rather than guiding learning.
4. *Institutional portfolios* serve to record and document achievements or non-academic activities, often for professional development planning or administrative purposes. They emphasize documentation and comprehensiveness rather than reflection or skill development.

2.2 The developmental portfolio

While all four types of portfolios are relevant to supporting lifelong learning and can be used for assessment, this chapter focuses on developmental portfolios (see references and further reading for examples of the other types; Bokhua et al. 2020; Clarke & Boud, 2026; Heeneman & Driessen, 2017). This choice is deliberate: developmental portfolios place students at the centre of their learning, actively involve them in the learning process, and encourage independent learning and reflection. By emphasising the process rather than just the product, developmental portfolios are particularly well-suited to support the cultivation of lifelong learning competencies. This does not mean that the educator is not a part of this process. Educators can play an important role in supporting the learning process to further increase learning gains by providing feedback (Hattie & Timperley, 2007) on the content, but also on the learning process itself. In practice, the portfolio is most beneficial when used as a formative assessment tool throughout a semester, allowing students to reflect, set goals, and receive feedback at multiple stages of their learning.

The developmental character of this portfolio is made explicit by structuring the portfolio around the personal development process (cited from Dujardin et al., 2024, p. 4; developed by Patel et al., 2013) as follows:

1. *Identifying gaps in competencies (skills, knowledge, and attitudes);*
2. *Prepare for learning by setting a (SMART) goal and identifying learning resources and opportunities;*
3. *Act on this plan;*
4. *Monitor the learning process;*
5. *Reflect on how the learning process can be improved and what the future learning needs are.*

This developmental portfolio is used to assess the lifelong learning competency self-regulation (see Chapter 2.15 of this handbook), rather than their mastery of individual competencies. Self-regulation is “*the self-directive process by which learners transform their mental abilities into academic skills*” (Zimmerman, 2002, p. 65).

In the model of Zimmerman (2000, 2002), self-regulation consists of three cyclical phases, namely the forethought phase, the performance phase, and the self-reflection phase. The forethought phase takes place before learning and refers to beliefs about the learner’s role in the learning process. During actual learning, in the performance phase, the learner must exercise self-control and self-observe to be aware of their learning process and enable improvement. Finally, in the self-reflection phase, the learning process is evaluated. These phases align closely with the personal development process implemented in our portfolio, outlined in the previous section.

The portfolio also aims to trigger the other lifelong learning competencies as defined by Van den Broeck et al. (2024):

1. *Autonomous motivation* (Chapter 2.17) means that learning is pursued because it is perceived to be enjoyable, but also because it is seen as useful. We aim to trigger this competency by communicating why the portfolio is useful and we

hope that students will experience its usefulness through their increased competency levels.

2. *Information literacy* (Chapter 2.16) can be triggered when students choose a concrete action that requires them to seek information about a specific competency, for example when they want to work on their ethical thinking skills by researching relevant topics.
3. *Initiative and perseverance* (Chapter 2.18) are required to successfully follow through with the portfolio and the learning process in practice.
4. *Learning beliefs* (Chapter 2.17) are included implicitly and will hopefully be influenced by helping students recognize their active role in learning, while learning strategies are triggered by asking them to choose their own approach to learning.
5. *Adaptability and resilience* (Chapter 2.15) are included implicitly and are necessary due to the longitudinal format of the portfolio.

3 Implementation and practical example

3.1 Context of the implementation

The portfolio discussed in this chapter was implemented in the curriculum of a three-year Engineering Technology bachelor programme at KU Leuven, Belgium. The faculty has multiple campuses which operate with a similar curriculum while allowing room for campus-specific implementations. The first trial of the portfolio was implemented and further developed in one campus in the context of an EU-funded Erasmus+ cooperation partnership called TRAINeng-PDP. Afterwards, a pilot in the first year of the bachelor programme was implemented at three more campuses.

The portfolio is implemented in a learning path called Engineering Experiences, which is a project-based, year-long module, systematically recurring in each year of the bachelor. These modules contain challenging and authentic assignments to integrate competencies acquired in other modules (e.g., designing an automatic window for a greenhouse), addressing both technical and professional skills. As the assignments increase in complexity, students expand their expertise through a mix of individual and group tasks that combine open and closed elements. The portfolio discussed in this chapter was implemented in a module with 110 students in the first bachelor year, 47 in the second bachelor year, and 44 in the third bachelor year. This decrease in cohort size is typical for the Belgian open-access higher education system, where relatively high first-year dropout rates reduce the number of students progressing to later years.

3.2 Content of the implementation

Students access the portfolio via their learning management system, in which it is implemented in two complementary digital forms: the portfolio itself and a self-assessment rubric. Both are outlined below.

The portfolio

The portfolio is built around the personal development process. At the start of the semester, students complete a self-assessment by filling in a rubric on transferable competencies and then defining a concrete action they will be taking that specific semester to improve one competency. During the semester, they report back by evaluating their progress and describing which steps they have taken. The portfolio focuses entirely on reflective entries and does not include additional artifacts or evidence. At the end of the semester, they complete a reflection in which they look back on the learning process and then look ahead to the next semester, which will involve a new portfolio and learning cycle. Over the course of the three-year bachelor programme, students repeat this process each semester, resulting in six iterations in total. The full content of the portfolio is included in Example 1.

Example 1. Portfolio context

Instructions — procedure

- *Fill in this form at the requested times during the semester.*
- *Follow the instructions as shown in each section. Tip: first write your answers in a separate document. This way, you won't lose valuable work if your browser crashes.*
- *When a section is completed, always send it to the instructor for feedback. You can find the name of your instructor at the top of the portfolio.*

We want to continuously improve the portfolio to better meet your needs as a student. Therefore, we ask for your permission to use the data from the portfolio for educational research purposes. More information can be found in the informed consent.

I agree

- ☐ Yes
- ☐ No

The personal development process

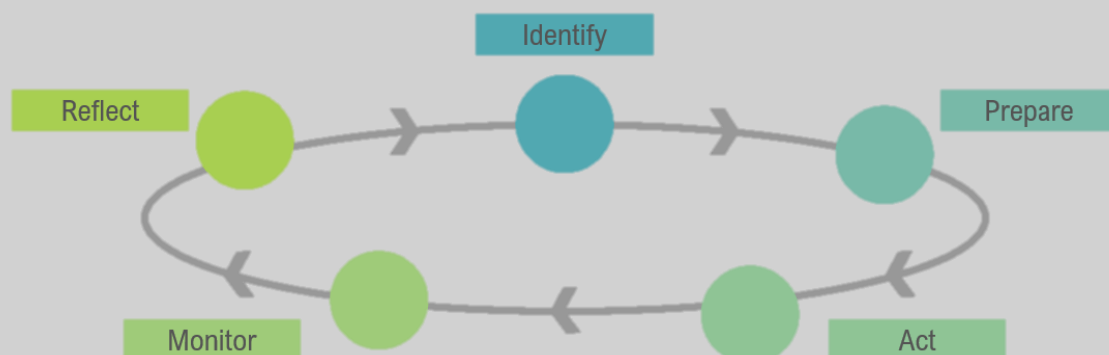


Figure 3.6.1: PDP process — Own work by Dujardin, 2023

Throughout this semester, you will go through the steps of the personal development process with the portfolio. We set deadlines for the different sections:

- 1. identify and prepare*
- 2. act and monitor*
- 3. reflect*

You can find the deadlines for each section at the top of this portfolio. To be on time, you must send the portfolio to the instructor for feedback.

Identify and Prepare

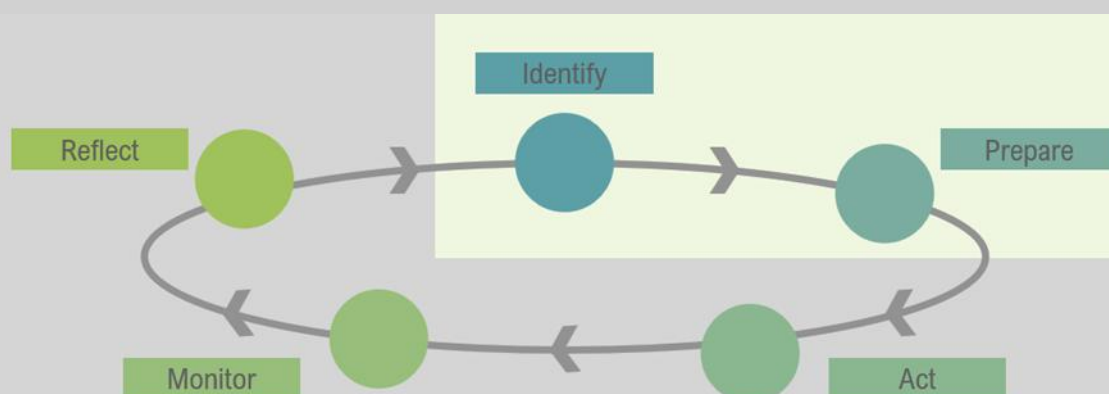


Figure 3.6.2: PDP process: identify and prepare — Own Work by Dujardin, 2023

In this section of the portfolio, you identify your strengths and weaknesses and create a plan to work on a chosen competency.

Go to the Professional Competencies Form to assess your proficiency in various competencies.

- You may not be familiar with some competencies. In this case, indicate the level you estimate to be most accurate.*
- If you think you fall between two levels, choose the lower level.*

Once you have filled in the rubrics, choose one competency to work on this semester. You don't have to choose the competency where you scored the lowest. You can also choose a competency that you value highly or one where you are already good and want to improve further.

Now create an action plan to work on this competency this semester. Some tips for creating an action plan:

- clearly describe which competency you will work on, your current level, and the level you want to achieve.*
- formulate a concrete plan and avoid vague goals. Describe specifically what, where, when, and how you will tackle it.*

- *you have one semester to complete this plan. Make sure it is realistic. You don't have to become an expert all at once. A small change can have a big impact.*

You now have the entire semester to execute your action plan. During the semester, you have to fill in the portfolio at two moments of their own choice. Send the portfolio to the instructor for feedback.

Act and Monitor

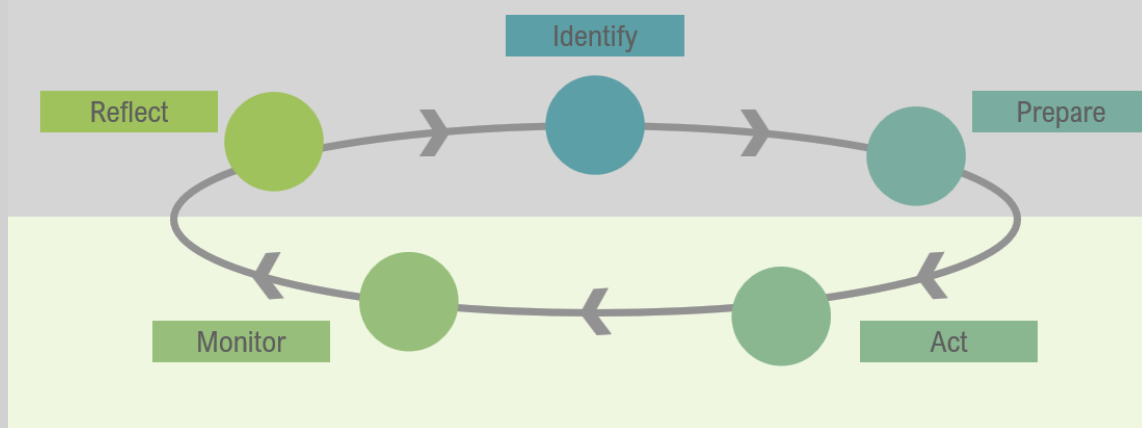


Figure 3.6.3: PDP process: Act and monitor – Own work by Dujardin, 2023

Fill in this section during the semester to track your progress. At two moments during the semester, you will have to answer the questions below.

- *For the first question, evaluate whether you have come closer to your goal. It's okay if you don't make progress at some point or even experience setbacks.*
- *For the second question, explain what actions you have taken to improve in this competency. Be specific. What did you try in which context, and what was the result?*

Send the portfolio to the instructor for feedback.

Moment 1

What progress have you noticed in your competency level for the chosen competency?

- ☐ *Significant decline*
- ☐ *Some decline*
- ☐ *No progress or decline*
- ☐ *Some progress*
- ☐ *Significant progress*

What specific actions have you taken to improve in your competency?

Moment 2

What progress have you noticed in your competency level for the chosen competency since the previous moment?

- ☐ Significant decline
- ☐ Some decline
- ☐ No progress or decline
- ☐ Some progress
- ☐ Significant progress

What specific actions have you taken to improve in your competency?

Reflect

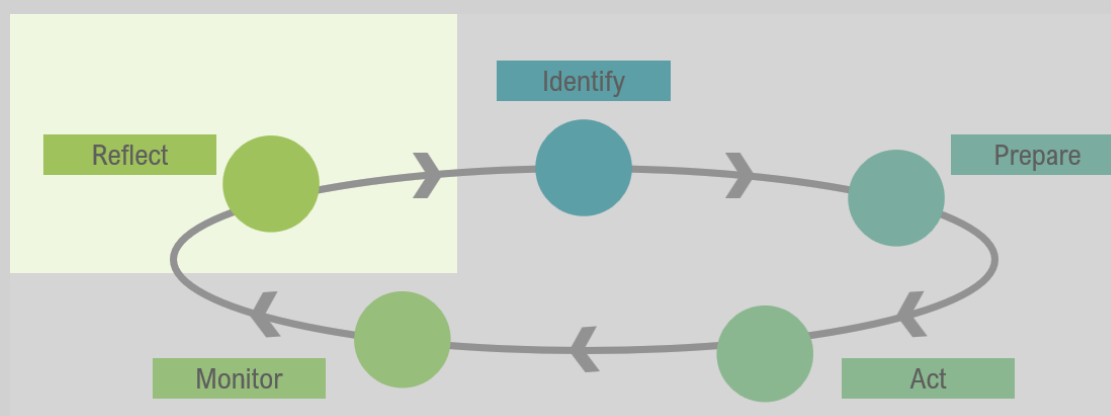


Figure 3.6.4: PDP process: Reflect — Own Work by Dujardin, 2023

This is the last section of the portfolio for this semester.

First, reflect on your learning process from the past semester.

- *Have you improved in your chosen competency? How do you notice this?*
- *Was your action plan a good plan? Did you make any adjustments?*
- *Are there other things you have learned about yourself, the learning process, or the competency?*

Next semester, you will create a new portfolio. Reflect on how you will approach it.

- *Are there other competencies you want to work on? Which ones and why?*
- *Will you approach it the same way?*

- *Are there other lessons from this semester that you will take into the portfolio for next semester?*

Send the portfolio to the instructor for feedback.

Table 3.6.1: Transferable competencies in the 'identify' rubric

<i>Competency</i>	<i>Indicator</i>
Lifelong learning	Self-regulation Motivation Information literacy Flexibility Learning strategies Perseverance
Reflection	Self-reflection Ethical thinking Critical thinking
Written communication	Correctness Targeting the right audience Structure Scientific writing
Presentation skills	Language use Clarity Targeting the right audience Speaking skills
Working with others	Leadership Contribution to teamwork responsibility
Stress resistance	Study stress Presentation stress Social stress
Innovative thinking	Problem solving Creative thinking Entrepreneurial thinking
Management	Project management Time management

The rubrics

In the 'identify' phase, the first phase of the portfolio, students use a form to assess their transferable competencies on four levels (1) beginner; (2) growing; (3) mastering; and (4) expert. These rubrics were developed using guidelines from our faculty, existing rubrics from other modules, as well as theoretical and empirical work on specific competencies.

To assist the students in selecting a specific competency to work on, they assess themselves on eight competencies, with at least two indicators each. Students are explicitly encouraged to work not only on competencies they still need to develop, but also on those they enjoy, find useful, or wish to excel in.

An overview of the competencies and indicators can be found in Table 3.6.1. The full rubric can be consulted on the Open Science Framework (Dujardin et al., 2026).

Feedback and evaluation system

Students receive the portfolio assignment in the first or second week of the twelve-week semester. There are three deadlines throughout the semester. The first deadline is in week 3 for the 'identify' and 'prepare' sections of the portfolio. For the 'act' and 'monitor' sections, there is one official deadline in week 10, but students are required to submit two progress updates between weeks 3 and 10. Finally, the 'reflect' section is due by week 12.

Educators, including teaching assistants and lecturers, give feedback using a reflection rubric based on Coppens et al. (2023) and Kember et al. (2008) (see Table 3.6.2.) throughout the semester. On top of the rubric, educators have the opportunity to provide additional feedback, which is especially useful when students score a 0.75 (for the grading see Table 3.6.2.). In this case they clearly put effort into the portfolio but did not get the full score because of a very specific reason. Since it is not possible to include every possible reason, this is noted in the written feedback. For example, when a student suggests a good concrete action, which is not completely realistic for the semester, they get such feedback. When the students did not ask for feedback through the system, the portfolio was not visible for the educator, and the portfolio was labelled as an 'empty form'.

The evaluation of the portfolio was included as a small percentage of the total score for each of the three Engineering Experiences modules, ranging from 5% to 10% depending on the bachelor year. It is also important to emphasize that one student always receives feedback from the same educator during each semester. The feedback and evaluation system described above was developed and tested in one campus and later implemented in stages in other campuses of our multi-campus faculty.

Table 3.6.2: Feedback rubric

<i>Part of the portfolio</i>	<i>Rubric</i>	<i>Grade</i>
<i>Identify and prepare</i>	○ Not filled out (on time)	0
	○ Engagement, no action	0.25
	○ Action, but not specific enough	0.50
	○ Concrete action	0.75
	○ Excellent concrete action	1
<i>Act and monitor</i>	○ Not filled out (on time)	0
	○ Insufficiently concrete description of actions	0.25
	○ Concrete description of actions taken without context	0.50
	○ Clear actions taken within context	0.75
	○ Clear actions taken with critical reflection	1
<i>Reflect</i>	○ Not filled out (on time)	0
	○ No reflection, a superficial answer to the question	0.25
	○ Basic reflection: somewhat reflective, but still superficial	0.50
	○ Good reflection: thoughtful answers	0.75
	○ Critical reflection on all questions	1

Competency development

The portfolio aims to foster competency development at two interconnected levels. At the first level, students focus on developing transferable competencies by selecting one competency from the rubric (see Table 3.6.1) to serve as the central focus of their portfolio. At the second level, students cultivate lifelong learning competencies (as outlined in Section 3) through engagement in an active, student-centred learning process. Because evaluation and feedback emphasise goal setting, process monitoring, and reflection, assessment primarily targets students' development of lifelong learning competencies.

In the feedback process it is important to note that students' self-regulation competencies are assessed, not the extent to which they master a competency. For example, in the 'reflect' part, a student with a critical reflection about why their leadership competency did not improve will get a higher grade than a student with a superficial description that shows their competency level in fact increased.

3.3 Results and outcomes

The following section contains data from the portfolios of the academic year 2023-2024. Firstly, we compare the different bachelor years of Campus A with a focus on their grades and the competencies they chose for their portfolio. Then, the grades of students in Campus A are compared to the grades of the students on a second campus (Campus B) to get insight into how the feedback and evaluation influenced students' performance.

Bachelor years

Table 3.6.3. provides an overview of student performance on the different components of the portfolio across the bachelor years. The results show that a considerable number of students achieve scores at the highest end of the scale. Performance is strongest among students in the second and third year, with a larger proportion reaching the top category. For example, on the 'identify and prepare' component, 87% of second-year students and 83% of third-year students scored at the highest level, compared to 57% of first-year students. On the 'reflect' part of the portfolio, it is notable that many first-year bachelor students do not fill out this part of the portfolio (29%) or get the second-highest score (29%).

Table 3.6.3: Grades over bachelor years (note: the mode for each bachelor year is in bold.)

<i>Identify and prepare</i>	<i>Bachelor 1</i>	<i>Bachelor 2</i>	<i>Bachelor 3</i>
Engagement, no action	2%	0%	4%
Action, but not specific enough	20%	10%	11%
Concrete action	10%	0%	2%
Excellent concrete action	57%	87%	83%
Not filled out (on time)	10%	0%	0%
Empty form	0%	3%	0%

<i>Act and monitor</i>	<i>Bachelor 1</i>	<i>Bachelor 2</i>	<i>Bachelor 3</i>
Insufficiently concrete description of actions	4%	0%	7%
Concrete description of actions taken without context	14%	0%	9%
Clear actions taken within context	18%	18%	20%
Clear actions taken with critical reflection	33%	69%	59%
Not filled out (on time)	22%	8%	2%
Empty form	8%	5%	4%

<i>Reflect</i>	<i>Bachelor 1</i>	<i>Bachelor 2</i>	<i>Bachelor 3</i>
No reflection, a superficial answer to the question	0%	0%	0%
Basic reflection, somewhat reflective, but still superficial	10%	3%	4%
Good reflection, thoughtful answers	29%	18%	26%
Critical reflection on all questions	18%	69%	46%
Not filled out (on time)	14%	0%	2%
Empty form	29%	10%	22%

Complementary to these performance outcomes, we analysed students' self-selected competencies. Students seem to choose competencies which are the most useful for them at that time. Most first-year students (59%) choose lifelong learning competencies or the time management competency and apply this to their learning during the academic year. In the second and third bachelor year, lifelong learning competencies decrease as choices (36% and 22%), but the other transferable competencies become more popular. Second-year students mostly choose written communication (13%), stress management (21%), and presentation competencies (8%). Third-year bachelor students are notably more focused on the competency working with others (30%).

Table 3.6.4: Semester 1 and 2 grades for first-year bachelor students from campus A and B (note: the mode for each bachelor year from each campus during each semester is in bold.)

	<i>Campus A</i>		<i>Campus B</i>	
<i>Identify and prepare</i>	<i>Sem 1</i>	<i>Sem 2</i>	<i>Sem 1</i>	<i>Sem 2</i>
Engagement, no action	8%	1%	27%	6%
Action, but not specific enough	20%	6%	45%	36%
Concrete action	12%	6%	21%	17%
Excellent concrete action	57%	64%	6%	19%
Not filled out (on time)	0%	16%	0%	6%
Empty form	2%	6%	0%	17%
<i>Act and monitor</i>				
Insufficiently concrete description of actions	8%	1%	15%	3%
Concrete description of actions taken without context	20%	6%	24%	8%
Clear actions taken within context	24%	6%	24%	42%
Clear actions taken with critical reflection	39%	49%	6%	14%
Not filled out (on time)	0%	16%	0%	25%
Empty form	8%	21%	30%	30%
<i>Reflect</i>				
No reflection, a superficial answer to the question	4%	9%	21%	3%
Basic reflection, somewhat reflective, but still superficial	12%	18%	12%	14%
Good reflection, thoughtful answers	35%	16%	18%	17%
Critical reflection on all questions	20%	30%	9%	14%
Not filled out (on time)	0%	1%	0%	0%
Empty form	29%	25%	39%	42%

Impact of feedback and evaluation

Table 3.6.4. contains an overview of the grades of the first-year bachelor students on campus A and B in semesters 1 and 2. In semester 1, only the students on campus A received feedback on their work and were evaluated. In semester 2, the students from both campuses received feedback and were evaluated. For campus A there is a slightly positive trend in the grades from semester 1 to semester 2, indicating that the students got better in the assignments as part of the portfolio and developed more of the necessary reflective competencies. At campus B the students scored slightly better in the first 'identify and prepare' part but then scored much stronger after receiving feedback in the 'act and monitor' part. In the last part of the portfolio, 'reflect' the scores also increased, but the number of students not filling out the portfolio remains notable.

Taken together, these findings suggest that a developmental portfolio can effectively support the development of students' self-regulation and reflective competencies across different stages of the bachelor programme. The improvement in portfolio performance over time and after receiving structured feedback indicates that students progressively develop stronger goal setting, monitoring, and reflection practices. It is worth noting that a notable proportion of students, particularly in the first bachelor year, do not complete the portfolio, especially in later stages of the semester. Furthermore, the evolving patterns in competency selection across bachelor years suggest that students increasingly align their learning focus with the developmental demands of their academic trajectory. This supports the assumption that portfolio-based learning can foster both lifelong learning competencies and contextually meaningful transferable skill development.

4 Recommendations for implementation

To conclude this chapter, we present recommendations informed by our approach to the developmental portfolio for fostering lifelong learning competencies, as well as by our experience with its implementation.

Make the learning process explicit. Although portfolios can be used to assess a wide range of competencies, we deliberately focused our assessment on lifelong learning competencies in order to make these processes visible and explicit for students. By foregrounding goal setting, action planning, process monitoring, and reflection, the portfolio helps students become more aware of how they learn and how they can continue to develop beyond individual modules. We believe that using a clear structure in the portfolio based on the five steps of the personal development process makes the learning process easier to keep track of and easier for the students to remember afterwards. We also used a visualisation in which the cycle of learning was clearly represented, highlighting how learning always continues.

Support reflection on self-selected competencies. Our findings show that students naturally select competencies that are most relevant to them at each stage of their programme. We recommend continuing to allow students this freedom of choice while providing structured opportunities for goal setting, process monitoring, and reflection.

This supports the development of lifelong learning competencies without restricting students' autonomy in selecting which skills to focus on.

Incorporate the portfolio throughout the curriculum. The portfolio has the most impact when it is consistently integrated across study years, rather than treated as a stand-alone assignment. The results show that students' focus on different competencies evolves over time; the first-year students often prioritise lifelong learning and time management, while students in later years shift towards stress management, communication, and teamwork. The portfolio scores also indicate clear growth from the first to the later bachelor years, with more students achieving the highest levels of performance, possibly due to practice with the portfolio exercises.

Differentiate portfolio focus across study years. Our results show that students' choice of competencies evolves as they progress through the programme. Educators might explicitly align portfolio expectations with these developmental needs, while still allowing room for personal choice. We applied this finding in the portfolio of another campus by asking students to choose between lifelong learning and writing competencies.

Use feedback systematically. The comparison across campuses indicates that structured feedback and evaluation help students improve their portfolio work, particularly in the 'act and monitor' and 'reflect' parts. At the same time, providing high-quality feedback on reflective writing can be time-intensive and challenging for educators. To ensure feasibility and consistency, we therefore recommend embedding feedback in a clear structure, supported by rubrics and exemplars, and allocating sufficient institutional time and support for this process (Beckers et al., 2016).

Allow informal and non-formal ways of learning. For many competencies, there are modules provided by the university. However, to really mimic learning in a professional career, we found it important to allow different types of learning. The concrete actions needed to be formulated according to the SMART formula but could also include trying out new techniques or learning from peers, for example. This way of learning allowed students to reflect on which learning strategy they wanted to use, which aligns more closely with how learning occurs in the professional context. There is often a specific time and a place for taking modules, but learning on the job and from colleagues can be equally valuable. In our portfolio, we found that most students opted for informal and non-formal learning, with students often relying on each other to provide feedback on their performance (e.g., presentation competencies) or to learn from each other (e.g., project management).

Encourage further strengthening students' strengths. Building on positive psychology (Anderson et al., 2024), we explicitly told students that they could work on the competencies they felt less confident about and needed to improve, but also on the competencies which they found to be interesting or fun or were already good at. We found that many students still opted to work on their self-perceived weaknesses, but some students did choose to work on their strengths, especially for the competencies 'leadership' and 'creative thinking'.

Describe clear expectations for competencies. In earlier versions of the portfolio, we used less extensive self-assessments, where students were given a competency (e.g. 'I am a teamplayer') and asked to respond using a Likert scale. This self-assessment was less useful because, as educators, we received little information about their perception of their competency level. Their point of reference for the competency was unclear: were they comparing themselves to other students, peers in general, their ideal selves, professionals, etc? Students might also differ in their understanding of a competency and what it means to be the highest level of a competency. Additionally, the students had to define a concrete action, but without the specific description of the competencies, this was harder to do. While it takes some time to develop a rubric, we do recommend this. We think that for transferable skills, our rubrics can be used or be adapted to fit the context.

Provide a safe space for sharing. Although engineering students are sometimes perceived as more rational and less emotional (Lönngren et al., 2023), the portfolio seemed to provide a context in which many felt comfortable reflecting on personal challenges and insecurities. Multiple students discussed topics such as loss of motivation, feelings of isolation, and disproportionate stress levels. The portfolio can be a safe space for them to work on these issues, and educators can advise them to contact student counselling services or seek help from friends or professionals.

Create clear expectations around feedback for educators. Providing feedback on portfolios, and specifically reflections, can be a challenge for educators both in terms of time investment and ensuring consistency and fairness across assessors (Beckers et al., 2016). For this reason, we optimized this process by using a feedback rubric with the option to give additional feedback. We recommend this approach because the rubric makes evaluating much easier and this approach is scalable to a larger number of students. Currently, we are trying out this method with students from another campus.

Taken together, these recommendations illustrate how portfolios can be implemented in ways that both respect the practical realities of teaching and foster competency development. By making the learning process explicit, integrating the portfolio throughout the curriculum, and creating clear expectations for both students and educators, portfolios become more than an assessment tool. They evolve into a structured learning environment that prepares students for the challenges of professional practice. While each institution and programme will need to adapt these ideas to its own context, our experiences suggest that a thoughtfully designed developmental portfolio can play a central role in cultivating lifelong learning competencies in engineering education.

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3.7

Inclusive and Ethical Assessment

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This chapter explores the principles and practical applications of inclusive assessment in engineering education, at a programme and module level, highlighting strategies such as Universal Design for Learning (UDL), Culturally Sustaining Pedagogy (CSP), and presenting a case study on choice in assessment. These approaches move institutions toward a culture of equity and opportunity for all learners. Assessments do more than measure student learning — they shape how students engage with content, develop skills, and demonstrate understanding. In engineering modules, ensuring that every learner has an opportunity to succeed is essential, yet traditional assessment practices often favour certain groups while leaving others at a disadvantage. Inclusive assessment goes beyond accommodating individual needs; it actively addresses systemic barriers to access, learning, and achievement. By offering flexibility in a diverse range of assessment modes and approaches, educators can create learning environments that are equitable, supportive, and motivating. Evidence shows that such flexibility, employing the ‘multiple means’ principles of UDL not only improves fairness but also enhances student engagement, confidence, and skill development.

1 Background: key terminology and frameworks

Meeting the differing needs of students and providing equity in assessment is crucial for effectively evaluating student learning in our increasingly diverse higher education landscape. In this chapter, we will explore inclusive approaches to assessment and provide practical examples of approaches which can be implemented by those who design and deliver engineering programmes, and modules. This chapter combines conceptual discussion with practical guidance and provides a useful guide for educators who wish to enhance their inclusive assessment design and practice. Inclusive feedback strategies are discussed in Chapters 2.12 and 2.13.

This first section will introduce the principles and concepts of inclusive assessment. Section 2 will explore practical strategies and ethical approaches to inclusive assessment, firstly outlining key considerations for inclusive programme planning and design for assessment, before focusing on the inclusive assessment case study technique of Choice in Assessment, with key considerations, examples from practice, and recommendations for implementation. The final section summarises the practical applications, giving recommendations for inclusive practice in inclusive and ethical assessment.

1.1 Inclusive education

Hockings' (2010, p. 1) definition of inclusive education states that it “*refers to the ways in which pedagogy, curricula and assessment are designed and delivered to engage students in learning that is meaningful, relevant and accessible to all. It embraces a view of the individual and individual difference as the source of diversity that can enrich the lives and learning of others*”.

Inclusive education is a dynamic process requiring institution-wide commitment to a systematic transformation of the culture, processes, and practices of the university, to overcome barriers to the presence, participation, achievement, and experience of all students, and to account for and celebrate the rich diversity of the learning community (Cardiff University, 2025). Oliveri and Wendler (2020) give an overview of admissions trends from an international perspective, suggesting that changes due to globalisation and the increase in international students across the globe result in a need for institutions to identify and plan for changes in the diversity of our students. In fact, higher education is more diverse than it has ever been. This diversity has been driven by widening access and participation agendas, and by equality legislation across the globe.

The changing landscape of higher education has made it more significant than ever to reflect on practice to meet the needs of the diverse student population. Knowledge of the diverse, intersectional identities of students is fundamental to design, teaching practice, and assessments. By acknowledging and understanding the diversity of students and anticipating the barriers that students may face whilst at university, educators can ensure they are providing learning opportunities that are authentic, relevant, and meaningful for all (Cardiff University, 2025).

For students, a crucial aspect of assessment revolves around the extent to which the format enables them to effectively demonstrate their achievement and potential. As noted by Thomas and May (2010, p. 13), inclusive assessment refers to “*the design and use of fair and effective assessment methods and practices that enable all students to demonstrate what they know, understand and can do*”. Inclusive assessment sometimes invokes the notion of ‘*justice*’ (McArthur, 2016, 2018), going beyond definitions of equality and equity to emphasize a system which offers access to both tools and opportunities for all learners. By anticipating the needs of students, the impact of crisis management and providing individual adjustments can be reduced.

1.2 Universal Design for Learning

Recognising and valuing diversity in higher education is not only about acknowledging students’ backgrounds, but also about rethinking how learning is structured to help ensure equitable access and success for *all* learners. As institutions continue to diversify, so too must pedagogical approaches, to reflect this reality. This shift requires changing from traditional learning approaches to proactive, intentional design that anticipates a wide range of learner needs and experiences. One such approach is Universal Design for Learning (UDL), which offers a practical framework for embedding inclusivity at the heart of curriculum and assessment development (CAST, 2024). The following section explores how UDL can serve as a tool for creating accessible and meaningful learning experiences that empower all students to thrive.

Inclusive education can be approached through the lens of UDL, as both intend to create a learning environment designed for a diversity of learners, rather than retrospectively making adaptations to accommodate specific students (Advance HE, 2018). UDL is a set of principles for curriculum development that give all individuals equal opportunities to learn. The goal of UDL is learner agency that is purposeful and reflective, resourceful and authentic, and strategic and action-oriented (CAST, 2024). UDL provides a blueprint for creating instructional goals, methods, materials, and assessments that work for everyone — not a single, one-size-fits-all solution, but rather a flexible approach that enables learning to be customised and adjusted for individual identities and needs (UDL on Campus, 2022).

UDL is thus a framework to guide the design of learning environments that are accessible, inclusive, equitable, and challenging for every learner. Ultimately, the goal of UDL is to support learner agency: the capacity to actively participate in making choices to meet learning goals (Cardiff University, 2025). UDL aims to change the design of the environment rather than to situate the problem as a perceived deficit within the learner. The UDL guidelines are set out in three sections: multiple means of engagement, multiple means of representation; pertinent to this chapter, assessment is addressed in the third section: multiple means of action and expression (CAST, 2024).

Learners differ in the ways they navigate a learning environment, approach the learning process, and express what they know. Therefore, it is essential to design for these varying forms of action and expression in assessments. For example, individuals

approach learning tasks in very different ways, and may prefer to express themselves in written text but not speech, and vice versa. It may not always be feasible to build in multiple options or choices for every activity or assessment, if a competence standard must be reached (Cardiff University, 2025). However, as far as possible, across a programme there should be diversity in assessment modes, that is, whether written, presentation, multimedia, practical and so on.

It should also be recognised that action and expression require a great deal of strategy, practice, and organisation, and this is another area in which learners will differ. In reality, there is no single means of action and expression that will be optimal for every learner; therefore, giving options for action and expression is essential (CAST, 2024).

Numerous traditional pedagogical approaches exist around creating assessments, with the three main categories each addressing learning in different ways (Davies, 2024a). Commonly, he notes that assessment is framed in terms of "*certification (assessment of learning — what learners know and can do), learning (assessment for learning — what learners need to study), and sustainability (assessment as learning — learners directing their own learning)*", as previously noted by Boud et al. (2018). Boud and Associates (2010) stress that assessment "*powerfully frames how students learn and what students achieve.*"

UDL asks practitioners to think about how learners are expected to act and express themselves. It suggests that options are designed that:

- Enable variety in interactions in responses, navigation, and movement, and enable options in interactions using accessible materials and assistive and accessible technologies and tools;
- Provide options and flexibility for students in the expression and communication of their learning, through multimedia and multiple tools for construction, composition, and creativity, challenging exclusionary practices;
- Build fluencies with graduated support (including scaffolding) for practice and performance, addressing biases related to modes of expression and communication;
- Support students in strategy development and the setting of meaningful goals, enabling students to anticipate and plan for challenges and organise information and resources (Cardiff University, 2025; CAST 2024).

Example 1 shows an example of series of additional prompts that can help you as educator reflect and enhance your use of multiple means of action and expression in teaching practice:

Example 1. Reflection for educators

Do you design for:

- *Choice or flexibility in responses, interactions, activities, and collaborations within sessions?*

- *A range of accessible resources, tools and technologies for expression of learning?*
- *Choice or flexibility in the mode students can demonstrate their knowledge or skills, such as written, spoken or multimedia?*
- *Scaffolded support for students to demonstrate essential skills in a particular mode, for example practice runs, formative tasks, and clear criteria for skills as well as content?*
- *Support for goal setting, strategic planning, time management and management of information, such as module and assessment maps, session plans and summaries of information resources?*
- *A diverse range of authentic but customised assessment methods accessible for EVERY student, while still aligning with the same module learning outcomes (Cardiff University, 2025; Davies, 2024b)?*

Inclusive, universally designed assessment processes provide for all students whilst also meeting the needs of specific groups. There are a series of research-informed recommendations for the programme-level design of inclusive assessment (Advance HE, 2018; Cardiff University, 2025; Tai et al., 2023). This research suggests programmes should employ:

- A range of assessment approaches that are accessible, non-discriminatory, and timely;
- A range of feedback approaches that are accessible, interactive, ongoing, and timely;
- Incorporation of student choice in assessment practices;
- Opportunities to critically engage with equality, diversity and inclusivity themes in assessments that relate to authentic real-life scenarios;
- Preparation, engagement, and support of students throughout the assessment process, that develops their assessment literacy;
- Opportunities for students to act as partners in the assessment and feedback process;
- A programme-level approach to the design, development, understanding, and coordination of assessment and feedback practices;
- Routine monitoring, review, and sharing of assessment practices that embed equality, diversity, and inclusivity.

Since programme learning outcomes need to be demonstrated by students and marking against these must be shown appropriately to maintain quality and professional standards, assessments need to be designed to substantiate them in a meaningful manner (Davies, 2024b). While UDL lays the principles for inclusion, it does not specify approaches to ensure learners from different cultures are equally regarded. Thus, we turn to principles of Culturally Sustaining Pedagogy (CSP).

1.3 Culturally sustaining pedagogy

As a social construct, assessment could be said to comprise practices and processes in which specific values and practices are reflected and enshrined, such as (in the UK, for example) rationality, individuality, objectivity, and written communication skills (Cardiff University, 2025). Recent work on inclusion and universal design of assessment has focused on the imperative to consider the socially constructed nature of assessment, through the lens of CSP (Hanesworth et al., 2019). Paris (2012, p.93) as cited by Hanesworth et al. (2019), defines CSP as being an educational approach that *"seeks to perpetuate and foster, to sustain, linguistic, literate, and cultural pluralism as part of the democratic project of schooling."*

Assessment forms and practices that are created through unquestioned and habitual use become normalised and can marginalise and exclude certain students and cohorts for whom such practices are unfamiliar or inaccessible (Cardiff University, 2025). In addition, assessments can be seen to hierarchise knowledge: in the necessary selection of content for assessments, practitioners subconsciously communicate to learners what disciplinary knowledge is important or valuable, and what is not. Assessment is indivisible from individual value judgements: they are designed and evaluated by practitioners, who have their own complex socio-cultural backgrounds, educational experiences, and intellectual and personal values (Cardiff University, 2025).

The concepts of inclusive education and assessment, UDL, and CSP are all closely linked, and directly inform the inclusive assessment approaches outlined for practitioners in Section 2. For practitioners, the following section outlines concrete steps it may be possible to take to implement these concepts in the design and implementation of assessments. The levels of agency individual practitioners have, and the barriers to implementation that may be experienced, will vary by programme, topic, institution, and country. However, as these strategies have been found in the literature to support inclusive assessment, implementing these approaches should be considered, whether immediately available, or, due to barriers to implementation, seen as a longer-term goal.

2 Inclusive assessment approaches

2.1 Programme planning and module design for inclusive assessment

There are core considerations when planning and designing programmes and considering the inclusivity of assessments: writing inclusive programme learning outcomes, mapping assessments by student journey, and identifying ethical, cultural, and linguistic challenges in assessment. This supports UDL by enabling 'multiple means of engagement' and 'multiple means of action and expression' by removing elements of the learning outcomes which restrict assessments to the expectation of fixed means of engagement in and demonstration of learning by students.

Writing inclusive programme learning outcomes

When designing programme learning outcomes, the conditions by which all students will be assessed are created, whatever their dimensions of diversity or characteristics. It is therefore essential that academic and competence standards of the programme are identified, and that learning outcomes are written in such a way that maximises flexibility, choice, and equity in assessments, to avoid unintended institutionalised discrimination (Cardiff University, 2025).

Writing inclusive programme learning outcomes ensures all students can demonstrate what they know or can do, to enable them to meet the learning outcomes to their potential. Once programme learning outcomes are mapped, module learning outcomes and assessments should then be mapped on to them, and module leads should be supported to understand the relationship between their module and the whole programme, and the relationship with the whole student journey. Identifying any challenges for diversity includes asking whether there are any modes of assessment which are over-represented (for example written versus speech, exam versus coursework)? Example 2 works through an example on how educators from a second-year engineering module in a UK university have assessed their learning outcomes on inclusivity.

Example 2. An inclusive learning outcome (Cardiff University, 2025)

To assess whether a learning outcome is inclusive, explore the components and expectations of the mode of assessment. For example, an engineering programme learning outcome might be that students are able to 'write a report outlining the design of a new building to provide a student learning facility to engender creativity, innovation, exploration and collaboration'.

Firstly, the educator must decide whether a written report is a competence standard for this programme. Is writing a report an essential skill? Could a student demonstrate their learning in another mode, such as an oral presentation?

The Equality and Human Rights Commission (2024, p. 78) states that, when considering disabled students, universities must "ensure that academic staff setting assessments know which aspects of their test are competence standards which must be met, and which aspects are the methods of assessment which may be reasonably adjusted."

Thus, if it can be justified that a written report is a core competence for this programme, then the learning outcome can remain. Otherwise, the performance criteria could be rephrased to enable multiple modes of action and expression (using the principles of UDL), with the student being able to complete an oral or written analysis. For example: 'conceive, design, and communicate the design of a new building to provide a 'student learning' facility to engender creativity, innovation, exploration and collaboration' (Cardiff University, 2025), rather than specifically stating to provide a written report.

Mapping assessments by student journey

To ensure inclusive, universally designed programmes, it is useful to identify over-assessment, bunching, early and low-stakes preparation for assessment types, potential options for adding choice in assessment, and adequate support for students undertaking new or innovative assessment types. This ensures equity in provision and an inclusive approach to support students to demonstrate their learning. In addition, when mapping, consideration should be given to what might be offered as alternative assessments for students, such as those eligible for adjustments due to disability, or those with emergencies or health issues.

To map the inclusivity of assessments on a programme, apply the principles of UDL in enabling flexibility and students' multiple means of action and expression across the programme. Identifying the modes of assessment open to students enables analysis of the range of different modes of assessment offered, and the potential barriers to attainment for groups of students. If analysed as a module-based timeline, as in Example 3 from a third-year engineering module, the dominance and flow of modes of assessment becomes apparent.

Example 3. Map of assessment modes in a module

	Module 1	Module 2	Module 3	Module 4	Module 5	Module 6
Year 1 Semester 1	Essay	Exam	Presentation	Practical Experiment	Group project written	Exam
Year 1 Semester 2	Exam	Essay	Essay	Exam	Written Portfolio	Essay
Year 2 Semester 1	Essay	Presentation	Essay	MCQs	Exam	Practical experiment
Year 2 Semester 2	Report	Exam	Essay	Essay	Essay	Essay
Year 3 Semester 1	Group project presentation	Essay	Written portfolio	MCQs	Research Project/ Dissertation	N/A
Year 3 Semester 2	Research Project	Practical experiment	Written Portfolio	Exam	Research Project/Dissertation	N/A

Figure 3.7.1: A module-based timeline of modes of assessment on an undergraduate engineering programme. Grid overview of assessment formats for six modules per semester over a three-year period, covering two semesters per year. Assessments are colour coded and cover essays, exams, presentations, practical experiments, MCQs, portfolio and group work (Own Work by Ceri Morris, 2025)

The figure illustrates that there is a reasonable range of assessment modes across the programme, with some oral, group, digital, and practical forms of assessment. However, semester 2 in years one and two all use written modes of assessment: students with dyslexia, or those with English as an additional language, might find this more challenging. Oral forms of assessment create fewer barriers to learning than written assessment modes for these students, so a change to the offer of choice in assessment mode, or a different mode in these modules, would be more equitable for diverse students.

Identify ethical, cultural, and linguistic challenges in your assessments

Assessment practices can often be created using normalised 'folk' pedagogy, i.e., using unquestioned and habitual forms that are culture-specific, which can marginalise and exclude students for whom such practices are unfamiliar and inaccessible. Analysis of assessments through the lens of UDL and CSP (Hanesworth et al., 2019), enables practitioners to be aware of an over-emphasis on traditional, familiar practices, such as the domination of the written essay and technical reports in UK universities, over those more familiar in other countries, such as oral examination or group work.

Effective assessment design acknowledges and incorporates students' funds of knowledge (Gee, 2018): the rich cultural, experiential, and community-based knowledge that learners bring with them into the classroom. By valuing these diverse forms of knowledge, assessments can move beyond narrow academic norms and instead offer meaningful, authentic opportunities for students to connect disciplinary learning with their own lived experiences. This approach might involve practitioners inviting students to draw on community practices, personal narratives, or real-world problem-solving strategies in assessment tasks. Designing assessments in this way not only affirms students' identities and strengths but also fosters deeper engagement, critical thinking, and a stronger sense of belonging within the learning environment (Gee, 2018).

Alternative assessments

Some countries, such as the UK, have enacted equality legislation, which requires universities take an anticipatory approach to support the varied needs that learners in the classroom will have. This means programmes proactively consider what adjustments might be made for students from the outset of programme design, rather than waiting until a crisis response to individual students' needs during a programme.

Students may have a disability, experience significant health issues, have caring responsibilities, or face a personal crisis, or may need to resit an assessment that cannot be replicated. Alternative assessment may therefore be required where a live assessment cannot be completed, including where reasonable adjustments cannot adequately mitigate disadvantage for disabled students, where verified health or personal circumstances prevent attendance, or where the timing of a resit (for example, during a break period) makes it impossible to reproduce activities such as group work or live presentations.

Programme or module leads should proactively identify alternative forms of assessment that assess the same learning outcomes. Identifying alternative assessments and adjustments that can be made to assessment methods from the outset, to meet the needs and challenges of students, addresses these requirements and ensures that these alternatives provide an equitable opportunity to demonstrate learning and skills. It should be ensured that assessment guides, marking criteria or rubrics (See also Chapter 3.4) are designed for all alternative forms of assessment, in addition to the standard assessment, and that these are shared and explained to students.

The scenario assessment in Example 4 illustrates how cultural assumptions embedded in test items can disadvantage certain groups of test takers, even when traditional statistical methods such as differential item functioning do not fully capture the source of that disadvantage. Specifically, it shows that for students undertaking a second-cycle degree engineering (master) programme, contextual knowledge, shaped by students' everyday experiences, can affect their ability to engage with an item as intended. When test items presume familiarity with specific systems, environments, or practices, they may inadvertently privilege some students while placing an extra cognitive burden on others. This can lead to construct-irrelevant variance, that is, differences in test performance that reflect background knowledge rather than the targeted construct, thus compromising both fairness and validity. Below is an example of how you can embed construct-irrelevant variance in a question when not all learners have the same lived experience with the context of a scenario-based assessment.

Example 4. Scenario assessment

Consider a science assessment item that presents a scenario involving municipal water treatment. The question may describe how water is collected, treated at a centralised facility, and distributed through public infrastructure, before asking students to evaluate the effectiveness of Environmental Protection Authority (EPA) standards for managing contaminants.

For students from urban or suburban settings, this scenario may mirror everyday life. However, for students in rural areas who rely on well water, where treatment and testing are handled privately and may not be subject to EPA regulations, the scenario might seem abstract or unfamiliar. These students must first work to understand a context that does not reflect their lived experience, before even beginning to apply their content knowledge.

As a result, what appears to be a straightforward question about environmental science may inadvertently test familiarity with urban infrastructure, introducing an unintended and inequitable barrier. This example underscores the importance of critically examining the cultural assumptions in test content, not just its statistical behaviour, to create assessments that are valid and inclusive for all learners.

2.2 Inclusive assessment case study technique: choice in assessment

Choice in assessment can take many forms: choice of topic, modes (such as written, presentation, multimedia, etc.), or scope, such as individual or team work. While choice of topic may be more familiar, the option of choice in mode or scope at a single point of assessment has been seen as more challenging, despite the potential to provide for UDL principles through multiple means of action and expression (Cardiff University, 2025).

Recent post-pandemic publications support choice in assessment, highlighting how positive changes made during the pandemic enabled the introduction of diversity and choice in assessment, and exploring how these might be sustainable in the future

through changes to assessment principles and practices, and collaborating on a programme-level approach to assessment (O'Neill & Padden, 2021).

In relation to student choice in assessment mode, research by O'Neill (2017) highlights the complexity of issues surrounding the implementation of student choice in relation to equity, perception of staff and students, careful and transparent alignment, and impact on outcomes, programme requirements, and standards of professional engineering institutions such as the AHEP4 or EUR-ACE standards.

Despite these complexities, O'Neill (2017) highlighted the positive impact of a limited choice for students, with the attainment of higher grades than those achieved by previous student cohorts who did not experience choice (Cardiff University, 2025). Similarly, Hockings' seminal review of the literature (Hockings, 2010) suggested that having choice in assessment mode enables students to deliver evidence of their learning in a medium that suits their needs, rather than in a predetermined and prescribed format, which may disadvantage an individual or group of students in the cohort. Research on student choice in assessment by Cardiff University highlighted similar themes (Morris et al., 2019). Similarly, case study research in progress at Cardiff University suggests very strong support for choice in assessment from students: on one engineering module offering choice, 87% of students supported choice in assessment at the start of the module, rising to 98% after the experience of submitting the assessment for the module. Students cited employability, diversity, and learning needs, the ability to work to their strengths, creativity, and engagement as the key reasons for these opinions. Students also highlighted the benefits of choice in assessment in helping them develop their decision-making abilities for future work and education. Similarly, staff identified benefits for the student experience, the potential positive impact on student satisfaction scores, developing a range of useful skills, meeting diverse needs, higher engagement, and more creativity as key factors in the arguments for choice in assessment.

In the following example, a year 3, first-cycle (bachelor) engineering design module offered free choice in the assessment mode that students could use to submit their problem-based learning coursework:

Example 5. Providing choice of assessment formats (Davies, 2024a)

Engineering practice often requires complex and interdisciplinary solutions, where authentic real-world challenges are approached through problem-based learning. These complex coursework design projects can pose an additional challenge around mapping learning outcomes across a diverse set of students. These challenges are not insurmountable but do require care and attention when designing appropriate authentic coursework assessments.

To ensure these challenges are addressed, use grading schemes together with detailed assessment-level criteria descriptors that meet learning outcomes, but without specifying the format, or mode, of the assessment. The aim is to design inclusive assessments for all students to evidence their potential, without the need for reasonable adjustments or further accommodations.

In this example, a design coursework assessment, students were allowed to choose between a range of flexible assessment options for their individual and group submissions. These assessment options included:

- *presentations — live*
- *videos — recorded*
- *storyboards*
- *digital simulations — models*
- *physical models*
- *animation*
- *technical written report*
- *a combination of the above*

To aid transparency, provide marking criteria schedules that clearly highlight and evidence equivalence across these diverse assessment formats, in an attempt to ensure equity while providing clarity for students and staff from the start of the module.

Ensuring equivalence of workload (Davies, 2024b) across various assessment formats is certainly an important discussion (Galvin et al., 2012), especially if some choices are perceived by students as needing less effort to achieve the same level of success and academic standard. Morris et al. (2019) found that students had reservations around being given a choice, being concerned about "fairness" around some modes of assessment. To gather student opinion on their experience of choice, students in this module were asked about their experience, and which mode of assessment was felt to be the most challenging. Interestingly, the results were equally weighted between the choices provided, namely presentation, oral, written report, or oral exam. This demonstrates that what is viewed as a preferred or a challenging mode of assessment is dependent very much on the individual. However, all students were in favour of the experience of choice.

Choice in assessment should be designed as part of a suite of varied assessments across the programme, with a range of supported opportunities for students to experience a range of modes, reducing anxiety and developing life and employability skills.

Consideration of choice in assessment mode necessitates attention to a core principle: the "*maintenance of academic standards is paramount and protected*" within national legislation (Bloxham & Boyd, 2007). So, while a student's choice of assessment mode aims to enhance equity and the potential to achieve similar outcomes, academic standards must be maintained. Therefore, students must demonstrate achievement of the same learning outcomes, whichever mode is selected.

Another key consideration is that of equivalence of workload: that each mode of assessment should carry the same workload, to ensure equity for all students. Equivalence has been debated in the literature and across the sector: tabular forms of equivalence have been criticised as an oversimplification of the issues in relation to

inclusive education, as different forms of assessment create different levels of student effort, depending on an individual's characteristics or needs. Marking criteria should demonstrate equivalence of the modes offered, through weightings, to ensure validity and equity of the assessment modes, and clarity for staff and students.

For any module where choice is offered, careful planning of opportunities for students to rehearse and discuss the choice they will select is important. Chan and Chen (2023) highlight the value of working with students as partners in assessment design, implementation, and feedback. Recent case study research at Cardiff University (in progress) suggested that students most highly value support for making the decision as to which mode to select, opportunities for question-and-answer sessions with the module lead or lecturers, and the availability of exemplars. These can be embedded in the content planning for the module, rather than being additional to it, and be made available asynchronously. Using a scheme of work ensures all those teaching on the module are clear what skills are being supported, as well as what content is covered.

To conclude this section, two additional descriptions are given of choice in assessment design. Example 6 and 7 both detail the design of assessments which employed choice in assessment mode as the summative assessment for all students on a first-cycle degree (bachelor) module. Example 6 presents a third-year engineering module in an EQF (European Qualifications Framework) level 6 degree; Example 7 a second-year module, both in UK universities.

Example 6. Implementation of choice in coursework assessment (Davies, 2024a)

This assessment explores the practical issues encountered when delivering inclusive assessments on a Year 3, EQF Level 6, 10-credit interdisciplinary engineering design module at Cardiff University (Davies, 2024a). The module focuses on the design of a multi-storey building using sustainability and net zero principles for a cohort of approximately 140 students. Students initially worked individually for six weeks before submitting an individual report, subsequently transitioning to groups of six and submitting a group written report after eleven weeks. Marking schemes were provided with UK assessment-level criteria descriptors that aligned with the content, teaching activities, and learning outcomes.

Being aware of the need to be more inclusive, existing assignments were developed into a variety of submission formats based on the original assessment marking criteria and learning outcomes, while offering improved choice and promoting diversity of assessment to suit student preferences.

Module learning outcomes — on completion of the module a student should be able to:

- Appraise structural solutions through rigorous evaluation;*
- Quantify the impact of material selection on appropriate design solutions;*
- Critically assess impact of sustainability, security, and inclusivity on conceptual design;*
- Generate realistic 3D structural solutions;*

- *Utilise individual and collaborative skills such as teamwork, mentoring, reflection, networking, and influencing;*
- *Appreciate the need to achieve radical decarbonisation at speed and scale, including societal and ethical impact.*

Davies (2024b) noted that "module LOs had to be achieved across the whole range of assessment formats being provided or be rewritten to span across the various assessment formats being offered".

Formative feedback is provided in the workshop sessions. The individual coursework assignment covers LO1 and LO4, while the group design assignment addresses LO2, LO3, LO5, and LO6.

Table 3.7.1: Excerpt of grading criteria for choice in assessment without indicating format of submission

Grade	Knowledge	Planning	Techniques	Presentation
<i>Outstanding 90-100%</i>	<i>An exceptionally comprehensive and detailed knowledge of the subject area; achieves a new level of understanding.</i>	<i>An exceptional amount was achieved through unusually ingenious and resourceful planning; highly professional; worked safely and well with colleagues.</i>	<i>Outstanding; developed new engineering principles or techniques.</i>	<i>An outstanding presentation: conveys the work and plans with exceptional clarity.</i>
<i>Excellent 80-90%</i>	<i>A thorough and detailed knowledge, beyond that required to solve the problem; significant new insights.</i>	<i>A large amount was achieved through careful and thoughtful planning; very professional; worked safely and well with colleagues.</i>	<i>Exceptional quantity and quality of work using sophisticated techniques; synthesis skills evidenced.</i>	<i>Excellent; uses creative and original means to convey the work and future plans.</i>

Students have free choice in the mode to complete and submit the assignment, and may select from a choice of flexible assessment options for their submission, such as:

- *presentations (live or recorded)*
- *written academic assignment*
- *written technical report*

- *videos*
- *storyboards*
- *multimedia or digital resources*

Students can also suggest their own formats in discussion with the module lead, to ensure they are able to meet the LOs.

The grading criteria were adapted to generalise and not specify particular submission formats, as shown in Table 7.3.1.

Example 7: Implementation of choice of written assessment — essay or presentation

At Cardiff University, 22 students in a second-year first-cycle degree module were given the choice of mode for submission for one assessment, as part of a pilot project regarding choice. Learning outcomes stated that on successful completion of the module, a student will be able to:

- *outline one key engineering policy;*
- *illustrate how this policy can be applied to contemporary practice;*
- *evaluate empirical and other data to explore the success of the policy;*

For the assignment, students had to select one engineering policy to illustrate how policies are enacted in engineering practice. The assignment could be completed as either:

- *a twenty-minute presentation (which includes five minutes of questions)*

OR

- *a written assignment, with a word limit of 2,000 words.*

Decision-making guidance was given in seminar 1. Guidance, practice, and discussion of presentations took place in seminar 2. Guidance, practice, and discussion of the written assignment took place in seminar 3.

Module evaluation data indicated an 89% satisfaction in the assessment (rising from 62% the previous year), with just one student 'not satisfied' with the assessment. Praise for the module included comments such as 'so inclusive' and 'this really helped me with my dyslexia, as I prefer to present'. The student who was 'not satisfied' was not comfortable with making a choice. Attainment data evidenced an increased attainment, from 8% fails in the previous year to none, and from nine students gaining a good mark (using the UK grading system, a 2:1 or above), to 17 students gaining a 2:1 or above.)

An excerpt of the grading criteria (demonstrating equivalence of presentation skills and written skills, and demonstration of key indicators for the top-grade boundary) is shown below:

Table 3.7.2: Excerpt of grading criteria for choice in assessment

Grade	Knowledge and understanding	Analysis and evaluation	Synthesis and critical thinking	Presentation skills	OR: Written communication skills
	Weight: 30	Weight: 30	Weight: 20	Weight: 20	Weight: 20
80-100%	<i>Shows a thorough knowledge of the principles and key concepts in the policy. Shows exceptional evidence of clear and original thought and can appropriately draw on and use a wide range of knowledge.</i>	<i>Can thoroughly describe and analyse concepts in the application of policy to practice</i>	<i>Shows exceptional evidence of clear and critical thinking. Sets out and supports their evaluation in relation to the enactment of the policy, showing awareness of competing viewpoints. Shows overall exceptional understanding and grasp of the complex interactions between policy and practice.</i>	<i>Exceptionally clear and confident delivery. Exceptional use of visual aids to supplement presentation. Excellent use of specialist vocabulary. Logical, coherent, creative and innovative presentation. Clear, consistent and accurate referencing.</i>	<i>Exceptionally clear and confident written skills. Excellent use of specialist vocabulary. Logical, coherent, creative and innovative written skills. Clear, consistent and accurate referencing.</i>

3 Key recommendations for inclusive and ethical assessments

This Section presents recommendations that practitioners may use as a checklist to support the development of fair and inclusive assessments. The recommendations are informed by both the literature and the authors' practical experience. They have been written broadly, to allow for flexibility based on institutional and national context. The authors acknowledge that some staff may not have the agency to implement all these recommendations. However, they are key aspirations when seeking to ensure all learners are assessed for what they know, and that assessment scores reflect students' genuine knowledge and skills, regardless of their diversity along other dimensions.

- Assessments are designed to address barriers to learning for traditionally excluded groups of students, applying Universal Design for Learning principles,

and anticipating the needs of potential students, to reduce the need for crisis management and individual adjustments.

- Programme learning outcomes are designed to be broad enough to enable flexibility in assessment, alternative assessments, and variety in assessment mode, within the limitations of the competence expectations of the programme.
- Assessments are mapped at a programme level, and designed to support students in timescales, flow, degrees of complexity, and variety in the modes of assessment.
- Cultural and linguistic diversity is considered in the design of assessments, in the language of texts, and in context of the assessment tasks, ensuring they are relevant, respectful, and accessible to a wide range of learners.
- Assessments follow the principles of multiple modes of action and expression where possible within quality expectations, and wherever possible choice and variety in assessment is enabled.
- Assessment briefs, criteria, and guidance follow the principles of constructive alignment that aligns teaching and learning activities with learning outcomes and assessment (Biggs & Tang, 2011) and use clear transparent language avoiding jargon, so that the requirements are clear to all students, and they understand the expectations for each grade boundary.
- Assessment design engages in collaboration and co-creation by involving students and staff in the development process, including the creation of examples, case studies, or scenarios that reflect their diverse backgrounds and lived experiences. This not only enhances relevance and engagement but also ensures that assessments are more inclusive, culturally sustaining, and representative of the student body.
- Programmes provide learning activities and formative assessments that build students' skills and understanding of the topic and task, readying them for summative assessments.
- Alternative assessments are planned from the outset, providing assessment criteria to all students, thus creating and inclusivity for all.
- There is a feedback strategy, with agreed terminology to be used in feedback. Feedback is personalised to the content and is clear and concise, relates to the assessment criteria, and is constructive and actionable.

For more inspiration and information on inclusive assessment in education, we refer the reader to the Education Development Toolkit of the Learning and teaching Academy of Cardiff University (Cardiff University,2025) and the UDL Guidelines (Cast, 2024).

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AI Statement

During the preparation of this work the authors did not make use of any AI tools.

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Part 4

Embedding at the Curriculum Level: Current State of the Art

4.1

Transferable Competencies and Skills as Fundamental to Engineering Curricula: Introduction and Lessons from Ten Institutional Case Studies

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Keywords: transferable competencies and skills integration, engineering curricula, institutional context, change management

There is an outmoded notion that technical knowledge is the substance of engineering and the basis for engineering education, while transferable skills and competencies are peripheral. Serving as the introduction to Part 4, this chapter sets the stage for ten institutional case studies that illustrate how such skills can be meaningfully embedded within curricula. We highlight their distinguishing contributions with a focus on leadership development, collaboration, communication, sustainability, and entrepreneurship. These cases showcase distinctive emphases on the contemporary skills and competencies currently embedded into engineering curricula within Europe and beyond. They reveal recurring patterns, including the use of problem-based learning and other active, enquiry-based and reflection-supported learning pedagogies, the cultivation of professional identity, and the necessity of alignment across multiple levels. Together, they provide engineering educators with a rich set of adaptable practices and issue a clear call to action: to champion and advance the deep integration of transferable competencies and skills within engineering education.

1 Introduction

In this part of the handbook, we present ten case studies from universities spread across three continents that are strategically implementing transferable competencies and skills into their engineering curriculum. These institutions are leading the way in taking on the myth long beholden by engineering education: technical knowledge and disciplinary skills are its 'hard' substances, while transferable skills such as communication, collaboration, teamwork, creativity, and ethical awareness are 'soft' extras to be taught in standalone modules. Like many myths, it speaks to a truth: technical knowledge is fundamental to practice because it distinguishes engineers from other professions. However, traditional educational approaches that have aligned with this thinking have left previous generations of graduates technically proficient yet underprepared for the complex, uncertain, interdisciplinary, ethically charged realities of practice (Habbal et al., 2024).

The historically prolific idea that transferable competencies and skills are important yet can be siphoned off and taught separately by experts outside of the discipline — such as by centralised educational specialists present in many large universities, or by consultants from the corporate world — is outdated, as evidenced by the case studies presented as chapters in this handbook part. Indeed, each study goes further in demonstrating that teaching transferable competencies and skills is not just equally important to teaching technical skills, but that these competencies are constitutive: part of the context required to learn engineering in pursuit of practice within the profession and woven into its very fabric. Although each institution tells a unique story, they all answer the same questions: how to best embed transferable competencies and skills into their engineering curriculum? To aid in comparing approaches, we asked authors to structure their chapters with guidelines: as well as describing the programmes themselves, they were asked to comment on how their work aligns to the competencies and skills presented and explored in the preceding parts of the handbook. Thus, they refer back to the relevant chapters and foundational concepts that consult on the wider and growing relevant literature, as well as giving space to explain their unique institutional context. All chapters conclude with a set of practical takeaways, including clear recommendations on what to do and what to avoid, as well as recommended further reading.

Each chapter demonstrates deep integration and embedding of transferable competencies and skills into curricula. However, they also reveal that there is no universal approach to transferable skill teaching. Their educational leadership stories differ in terms of both presentation and content, as well as differentiating histories, stakeholders, environments, culture, policies, personalities, and myriads of other factors which can influence the design of embedded skills curricula. Anticipating this, we asked chapter authors to describe not only their initiatives, but aspects of their context they thought important and which influenced how they designed and developed their own curricula, revealing fascinating insights into their universities and associated educational culture. This should help you appropriately interpret them in light of your own context and draw on them selectively to embed transferable

competencies and skills now, or in the future when the opportunity arises. This chapter introduces each case study, identifies recurring themes, and finishes with a call to treat transferable competencies and skills as constitutive, rather than ancillary elements of engineering curricula.

2 The chapters: institutional case studies

To help you to prioritise your reading, we provide a summary of each chapter together with what we've identified as its distinguishing contribution.

Denmark's *Aalborg University* (Chapter 4.2) has championed problem-based learning (PBL) for over fifty years, helping to establish it as the signature pedagogy for teaching transferable competencies and skills not just in Europe but globally. It was therefore appropriate to open this Part by inviting this university to share its extensive experience and research. Guerra et al. detail their groundbreaking PBL model, mapping its 48 competencies to those outlined in this handbook. The learning activities are centred on complex problem solving, project management and leadership development, collaboration and co-creation, interdisciplinary engagement, and professional identity and agency. Drawing on decades of lessons learned, they offer a comprehensive set of recommendations for the reader to adopt or adapt, many of which are echoed in subsequent chapters.

Chapter 4.3 by Craps et al. from *KU Leuven* in Belgium is the first of the many chapters in this Part which outlines a competency-based framework to help students with collaboration in teams and to progress their attainment of transferable competencies and skills. They present six clusters of competencies: team dynamics, project management, communication, innovation, entrepreneurship, and ethics. They embed these skills across a multi-campus curriculum. Their distinguishing characteristic is engineering identity development, supported by e-portfolios and authentic projects.

In Scotland, at the *University of Strathclyde* (Chapter 4.4), the Vertically Integrated Projects for Sustainable Development programme (VIP4SD) integrates transferable competencies along with entrepreneurial and sustainability skills. Strachan et al. describe their methodology, which includes structured workshops and assessments. Significantly, VIP4SD is an adaptation of the established Vertically Integrated Projects (VIP) model, which originated at Georgia Institute of Technology (USA), and has since been adopted internationally by numerous universities who have come together to form the VIP Consortium. This highlights the increasing viability of sharing and unifying around global best practice models for embedding transferable competencies and skills.

Gómez-Puente et al. from *Eindhoven University of Technology (TU/e)* in the Netherlands (Chapter 4.5) position self-directed learning (SDL) as the backbone of a longitudinal professional and personal development (P&PD) learning trajectory within their Industrial Design bachelor curriculum. They integrate the SDL subskills of goal setting, planning, self-regulation, reflection, and professional identity into a competency-centred and problem-based learning environment. Their distinguishing characteristic is a whole-curriculum, change-managed redesign that embeds SDL

across projects, coaching, mentoring, and assessment, enabling students to take ownership of their learning pathways and evolve as adaptable, reflective designers prepared for lifelong learning.

The Integrated Engineering Programme (IEP) at *University College London (UCL)* in the UK (Chapter 4.6) has gained attention in engineering education literature and communities globally for its exemplary model of skills integration across all engineering disciplines using various forms of project-based learning, including challenge-based learning. Nweke et al. share the implementation of this approach through a typical engineering degree: their undergraduate degree programme in Biomedical Engineering. Notably, the IEP illustrates the necessity of developing transferable skills incrementally through a progression model that is associated with dedicated teaching and assessment of such skills within and alongside student engagement with disciplinary and interdisciplinary scenario-, project-, and challenge-based learning opportunities.

Cooke et al. from *University of Birmingham* in the UK (Chapter 4.7) present a multi-level framework aligning institutional graduate attributes, faculty-level professional identity formation, and curriculum-level competencies development through integrated design projects (IDPs). Skills are conceptualised distinctly at each level — as qualities, identity, and competencies — creating coherence across the student experience. Their distinguishing characteristic is the positioning of professional identity and student belonging as developmental and transferable competencies, embedded through psychologically safe teamwork, inclusive practices, and challenge-based learning across interdisciplinary engineering cohorts.

At the *University of Melbourne* in Australia (Chapter 4.8), Rios et al. showcase the development of teamwork skills through three distinct case studies. They developed the Teaching, Practicing and Assessing Teamwork (TPAT) framework, which conceptualises the demonstrable individual behaviours of effective team practice. The case studies across their programmes collectively demonstrate the utility of TPAT as a tool for reflecting upon and enhancing existing teamwork teaching, as well as driving the creation of new modules and assessment methods. The chapter highlights the important and powerful role of developing and applying evidenced-based conceptual frameworks which draw on contemporary engineering education research.

Between them, the *University of Technology Sydney* and *University of Sydney* in Australia (Chapter 4.9) have two decades of experience in embedding transferable competencies and skills at scale. Machet et al. describe a dedicated five-unit sequence integrating skills across project units and co-curricular requirements. Both show that structure matters less than the principles of embedding, scaffolding, authenticity, and evidence-based assessment.

Ramirez et al.'s E-Lead programme at *University of Texas El Paso (UTEP)* in the USA (Chapter 4.10) integrates skills by broadly framing them as leadership and entrepreneurial competencies. The programme centres student development on personal attributes adapted from the US military. This American context, involving

students from disadvantaged Hispanic backgrounds, offers a unique example of embedding transferable competencies and skills with a strong entrepreneurial focus to facilitate upward social mobility.

At *Cornell University* in the USA (Chapter 4.11), Hutchison et al. position communication as inseparable from engineering practice. Their Engineering Communications Program (ECP) embeds core communicative competencies: context, design, social action, and identity, into engineering curricula through both tailored teaching and flexible partnerships with disciplinary subjects. Distinctive to their model is its emphasis on authentic, situated communication tasks and discipline-specific genres, reinforced by longitudinal self-efficacy studies showing measurable gains in students' communicative confidence and capability.

Additionally, while all chapters address targeted redesigns of a specific degree programme or module, some also consider integration across all engineering disciplines or an entire institution, including non-engineering subjects (Fig. 4.1.1).

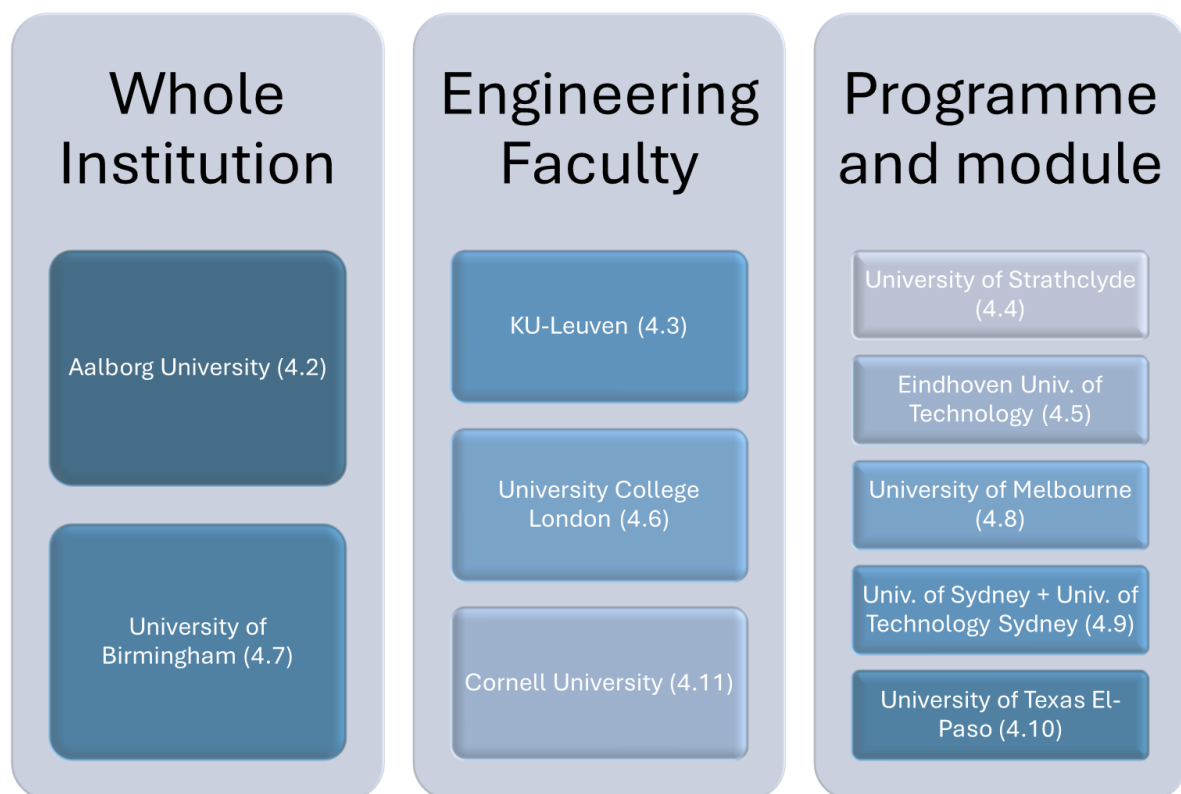


Figure 4.1.1: The ten case studies in this part with their chapter numbers, categorised according to the highest level of integration detailed (Own Work by Cooke and Tilley, 2026)

3 Recurring themes

When editing this Part of the handbook, we identified some common threads, which are important to set out in advance as a collective reflection of the integrative approaches to competencies and skills teaching and assessments within engineering curricula.

Authentic integration. All institutions are treating transferable competencies and skills as constitutive of engineering practice, not as auxiliary skills.

Authentic pedagogy. Problem-based learning (PBL) and its derivatives are frequently observed pedagogies used to simulate authentic engineering practice. All chapters demonstrate that transferable competencies and skills should be learned in real or simulated professional contexts.

Identity development. The curriculum is an intentional part of the student's professional identity formation. Many case studies focus on who students are and who they will be, framing transferable competencies and skills as a core component of becoming an engineer.

Skill progression. Mastery of skills requires a deliberate progression model. Many initiatives demonstrate how skill learning is intentionally scaffolded across years and levels of study, ensuring they are revisited and deepened.

Shared resilience. Different institutions with widely different contexts can achieve similar outcomes due a shared vision to embed transferable competencies and skills into the curriculum. These institutions have persisted and flourished because their work is underpinned by a resilient conceptual framework which supports their contribution to this shared vision.

Multi-level alignment. While each institution utilises different conceptual frameworks, they share the principle of multi-level alignment, which purposely connects the high-level institutional vision to the practical design and delivery of the curriculum.

Change management. All these case studies are continuous works in progress, as changing priorities and new understandings require a commitment to a constant cycle of innovation, scaffolding, measurement of impact, and revision. This highlights the need for strong overarching change management leadership with a mandate to remain flexible, reflexive, and future-focused when introducing and maintaining the embedding of transferable competencies and skills in curricula.

4 Final advice on institutional implementation of transferable competencies and skills

When universities or their degree programmes frame transferable competencies and skills as supplementary, they compromise their students' future. These competencies enable sound judgement, collaborative problem solving, and responsible action in contexts defined by uncertainty and trade-offs. Therefore, they are not supplementary; they are constitutive. Every Chapter within this Part of the handbook is evidence that deep curriculum embedding is possible, scalable, and transformative.

They offer not just inspiration but concrete strategies and resilient structures for the reimagining and restructuring of taught engineering degree programmes. This is not about teaching workshops at the margins; it is about integrating authentic tasks with real audiences, mapping outcomes across modules and programmes, and making competencies visible within the learning outcomes and developmental through credible assessment.

It must be mentioned that there are future challenges and significant opportunities for impact involving helping students to uncover, recognise, and articulate these embedded competencies and skills. Aimed at capturing the intrigue of keen practitioners and responding to the need for more accessible evidence-based guidance within higher education institutions, the chapters each tell a unique, well-informed, and experiential story. By comprehending and reflecting on each contribution, you will gain a fresh understanding of what could and what might not work in your own context.

The constraints are familiar: packed curricula, staff who lack confidence to lead pedagogical innovation, students who initially question the relevance of explicit skills teaching, and accreditation frameworks that can feel constraining. Yet change consistently takes root through focussed pilots, careful evidence gathering, and coalitions that bridge faculty, students, industry partners, and accrediting bodies. As durable structures, such as shared rubrics, cross-module themes, programme level assessment, and recognition for educational leadership, replace reliance on individual champions, momentum becomes self-sustaining. Movements precede mandates: practice, proof, and shared language generate the legitimacy that leadership then codifies.

The case is clear. Transferable competencies and skills must be treated as core competencies inseparable from technical learning and professional identity formation. Institutions that act on this imperative will graduate engineers equipped not only to solve complex problems, but to lead, adapt, and act ethically in service of society. Change often starts with grass-root effort and commitment, articulating the real need, and then planting ideas about how to address it, all the while working hard together to overcome obstacles. The concluding message is unapologetically direct: do not wait for permission. Commit to integration, build evidence, and institutionalise the gains. That is how engineering education moves beyond proficiency towards purpose. Movements create mandates, movements do not wait for mandates.

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4.2

A Systems Approach to Transferable Skills in PBL-Based Engineering Education: The Aalborg University Case

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Keywords: *problem-based learning, problem design, project work, teamwork, interdisciplinarity, professional identity, professional agency*

This chapter advances a systems approach to transferable skills in engineering education, using Aalborg University's project-organised problem-based learning (PBL) model as a central case. It highlights key competencies — complex problem solving, project management, leadership, collaboration, co-creation, interdisciplinarity, and professional identity, and professional agency — as essential for addressing contemporary challenges. Drawing on three decades of research, the chapter shows how these skills can be cultivated through authentic problems, project work, and teamwork. Each competency is defined, grounded in theory and empirical evidence, and illustrated with examples from practice, along with typical challenges and practical guidance for educators. Together, the chapter argues that PBL supports progressive, authentic, and reflective competency development. It concludes with research-informed recommendations for embedding transferable skills in engineering programmes, emphasising constructive alignment, scaffolding, interdisciplinarity, psychological safety, and real-world engagement to prepare adaptable, collaborative, and agentic engineers.

1 A systems approach to transferable competencies and skills in PBL-based engineering education

1.1 Why transferable skills matter

Engineering graduates nowadays need more than disciplinary expertise to thrive in professional practice and to address urgent societal challenges such as climate change, digitalisation, and sustainability transitions. Alongside strong STEM foundations, engineers must also develop transferable competencies and skills such as problem solving, project management, collaboration, interdisciplinarity, and the ability to negotiate their professional identity, and exercise professional agency (European Commission, 2019). The question for educators is how to support the development of these skills systematically, not as isolated add-ons but as an integrated and continuous part of the curriculum. This chapter draws directly on three decades of research conducted at Aalborg University (AAU), where systemic PBL has been continuously developed, studied, and refined. Our approach to transferable competencies and skills is research-based and integrates insights from multiple perspectives, including students' learning processes, educators' practices, and institutional leadership strategies.

1.2 PBL as a systemic foundation

Problem-based learning (PBL) offers a system-oriented foundation for developing transferable skills. Since its foundation in 1974, AAU has implemented a university-wide problem-based, project-organized learning (hereafter PBL) model, making transferable skills a defining feature of its engineering programmes. Every semester, students work in small groups, learning by solving real and authentic problems through project work. In the 1970s, PBL emerged from the need for graduates to possess practical, ready-to-use skills (know-how) when transitioning into the labour market. PBL evolved informed by research and to accommodate changes reflecting national and European higher education policies (e.g., the shift from individual to group-based exams and the implementation of the ECTS system through the Bologna Process), as well as societal and professional trends (e.g., digitalisation, the COVID-19 pandemic, interdisciplinary learning). Even though these trends have shaped AAU's PBL curriculum and practice, three interrelated dimensions remain present: problem, project, and teamwork (Aalborg University, 2015).

Together, these dimensions, as described in Table 4.2.1, create a curriculum-wide system in which transferable skills are developed through authentic practice, iterative cycles of learning, and reflection. Within this model, educators take on multiple roles: not only as researchers in their engineering fields, but also as lecturers who provide disciplinary input, and as facilitators who support project teams and assess student learning outcomes of project work (Aalborg University, 2015). A system approach to transferable skills means that competency development is integrated across the curriculum, not confined to individual modules; interdependent, recognising connections between skills such as teamwork, reflection, and project management; progressive, offering students repeated opportunities to build skills from basic to

advanced levels; and contextualized, aligning learning with authentic problems and professional challenges.

Table 4.2.1: Interrelated dimensions of Aalborg's PBL Curriculum

<i>Problem</i>	Students engage with real-world, contextual challenges that may be disciplinary, multidisciplinary, or fully interdisciplinary. Addressing these problems often involves interacting with stakeholders beyond the university, linking academic learning to societal needs.
<i>Project</i>	Students work in semester-long, project-organised formats where they apply and integrate knowledge to design, analyse, and propose solutions. Projects act as the main vehicle for combining disciplinary expertise with transferable skills such as project management, collaboration, and communication.
<i>Teamwork</i>	Students collaborate in teams throughout the semester, supported by facilitators and structured reflection and feedback. Teams typically range from two to six members, with larger groups common at bachelor level and smaller teams at master level.

For educators, this means designing environments where transferable skills are embedded in problems, projects, and teamwork, not left to chance or treated as optional extras of student learning.

1.3 Aalborg University PBL competency framework as an example

In this chapter, we refer to transferable competencies and skills as PBL competencies. The terminology is rooted in the Danish Qualification Framework for Higher Education (NQF-HE) and aligned with the European Qualifications Framework (EQF). Both define competencies as the capability to work responsibly and independently, and to apply knowledge and skills in study or work contexts (Danish Ministry of Higher Education and Science, 2008). Thus, *competency* combines knowledge in a field with the ability to act on that knowledge, making it actionable and context dependent. Research carried out at AAU identifies four overarching pillars of PBL competencies (Holgaard & Kolmos, 2019):

1. *Problem-oriented competencies*. Engaging with authentic problems across disciplines (e.g., problem identification, problem types, criteria for problem solving, ethics, sustainability).
2. *Interpersonal competencies*. Collaborating with peers, supervisors, and stakeholders (e.g., team building, team culture, team roles, communication strategies, decision making, conflict management, constructive dialogue).
3. *Structural competencies*. Organising and managing projects, roles, and methods (e.g., project management, delegation of work, time and activity management).

4. *Metacognitive competencies.* Reflecting on one's learning and adapting based on experience (e.g., reflection, values clarification, personal learning goals, anticipation for future).

The four overarching PBL competencies pillars, or areas, are each broken down into 12 specific competencies (Habbal et al., 2024, p. 216). Together, these four pillars outline 48 competencies. Not every student develops all competencies equally, but the framework shows how PBL provides diverse opportunities for competency development, depending on how curricula and projects are designed (Habbal et al., 2024).

Practitioner takeaway

The AAU case shows that transferable skills are best developed when embedded in authentic problems, project work, and teamwork, rather than taught separately. Educators play a key role, balancing research expertise with their roles as lecturers and facilitators.

2 Implementation of the systems approach to transferable skills in PBL-based engineering education

Building on a systems perspective, the AAU model shows how PBL dimensions emphasise different aspects of transferable skills. Table 4.2.2 shows how problems, projects, and teamwork provide distinct yet interconnected pathways for developing transferable skills.

Table 4.2.2: How problems, projects, and teamwork foster transferable skills

<i>Dimension</i>	<i>Key transferable skill</i>	<i>How they are fostered</i>
Problem	Problem solving, critical thinking, contextual awareness, interdisciplinarity, innovation	Students engage in authentic real-world problems, often requiring cross- or interdisciplinary perspectives and interaction with external stakeholders.
Project	Project management, planning and organisation, decision making, communication (written and oral), integration of knowledge	Semester-long projects require managing time, tasks, and deliverables, applying disciplinary knowledge, and presenting results to diverse audiences.
Teamwork	Collaboration, co-creation, leadership, negotiation, conflict resolution, professional identity, professional agency	Teamwork demands coordination, shared responsibility, reflective practice, and developing the ability to take initiative and act within professional roles.

2.1 Complex problem solving

Why does it matter?

In a world increasingly shaped by sustainability challenges and rapid socio-technological transitions, complex problem solving is a core competency in engineering, complementing specialized technical knowledge. The OECD (2024) highlights the labour-market value of communication, interpersonal skills, and problem-solving skills, while the World Economic Forum (2025) emphasises problem solving and resilience as critical for success. Our understanding of problems, problem-solving skills, and their importance can be summarized by answering the following questions:

- *What counts as a problem?* A problem is an unknown situation requiring resolution, ranging from simple tasks to complex societal challenges, and is meaningful or valuable to solve (Jonassen, 2011).
- *What are problem-solving skills?* They are part of broader cognitive and transferable skills — such as reasoning, critical thinking, and systems thinking — that enable tackling complex, real-world, and interdisciplinary challenges (Holgaard et al., 2017; Jonassen, 2011; OECD, 2024).
- *Why are they important?* They help individuals adapt, innovate, and address societal challenges while remaining agile in a changing professional landscape

How PBL supports complex problem-solving skills

In PBL, problem framing is central: it serves as the driver of student learning. Well-designed problems contextualise knowledge, challenge students to connect disciplines, and open reflection on societal and ethical dimensions of technology (Guerra & Holgaard, 2019; Svihla et al., 2021). We refer to this process as problem design, beginning with real and authentic situations that may be disciplinary, cross-disciplinary, or interdisciplinary in nature.

These situations often involve contact with external stakeholders, further anchoring learning in societal contexts. Several frameworks can support students in developing complex problem-solving skills. At AAU, problem design is widely applied, but other complementary approaches such as design thinking and the Cynefin Framework (Snowden & Boone, 2007) have also proven valuable (Table 4.2.3).

All three frameworks in the context of engineering education provide a conceptual scaffold for cultivating students' ability to engage with real-world, ill-defined problems. They draw on constructivist learning, systems thinking, iterative learning, and epistemological pluralism, recognizing that complex problems require diverse ways of knowing and transdisciplinary integration. These principles align closely with PBL principles, where students work in teams to solve open-ended, authentic problems. Educators can use these frameworks to help students to recognise the nature of a problem; select appropriate strategies (e.g., stakeholder engagement, interdisciplinary collaboration); reflect on decision making and adapt approaches; and develop resilience and adaptability (Guerra et al., 2025; Habbal et al., 2024; Snowden & Boone, 2007; Svihla et al., 2021).

Table 4.2.3: Example of frameworks to foster complex problem solving

<i>Frameworks</i>	<i>Description</i>
Problem design	Structured in three stages: problem identification, analysis, and formulation. Uses inquiry-based approaches (e.g., 5W1H: what, why, who, when, where, how). Students conduct literature reviews, stakeholder interviews, and fieldwork to define solvable problems within real-world constraints (Holgaard et al., 2017).
Design thinking	Follows five stages: empathise, define, ideate, prototype, and test. Encourages empathy, user orientation, and consideration of ethical, societal, and environmental dimensions. Promotes creativity and iteration in engineering design (Habbal et al., 2024).
Cynefin framework	Categorises problems into five domains: simple, complicated, complex, chaotic, and confused (Snowden & Boone, 2007). According to Snowden and Boone, " <i>Cynefin, pronounced kunev-in, is a Welsh word that signifies the multiple factors in our environment and our experience that influence us in ways we can never understand</i> " (Snowden & Boone, 2007, p. 2). Supports decision making by recognising cause-effect relationships and selecting strategies: best practices, expert analysis, experimentation, stabilisation, or sense-making (Habbal et al., 2024).

Integrating frameworks such as problem design, design thinking, or the Cynefin framework can greatly enrich students' capacity to address ill-defined, real-world problems. At the same time, successful use of these frameworks depends on how educators design, scaffold, and assess the learning process (Table 4.2.4).

Table 4.2.4 Educator guide: Fostering complex problem-solving skills

<i>What students gain through PBL</i>	<i>What educators need to consider</i>
Recognise the type and nature of a problem	Align learning outcomes with complex problem-solving competencies
Select strategies to understand the context of the problem in depth and inform decision-making processes.	Scaffold student in designing authentic problems and allocate sufficient time for exploration and framing
Reflect on decision making and adapt approaches during the process	Balance disciplinary teaching with facilitation and coaching roles
Build resilience in navigating uncertainty and complexity	Ensure assessment captures both disciplinary knowledge and transferable skills

Practitioner takeaway

For educators, fostering complex problem solving goes beyond assigning exercises. It involves designing authentic, real-world problems that prompt students to integrate knowledge, engage stakeholders, and reflect on their approaches. Frameworks like problem design, design thinking, or the Cynefin framework offer useful scaffolds when aligned with outcomes, activities, and assessment. Through repeated engagement with ill-defined problems, students build analytical and creative abilities, alongside resilience and adaptability essential for their professional futures.

2.2 Project management and leadership

Why do they matter?

Engineering graduates are expected to manage complex projects and lead collaborative teams addressing societal challenges. In engineering education, project management and leadership are often mentioned together, but they are not identical (Routhe et al., 2024). Management is about planning, structuring, and monitoring processes, while leadership is about setting direction, motivating others, and enabling change (Kotter, 1990). In practice, the two overlap: leaders must sometimes manage, and managers must sometimes lead (Bass, 1990). Our Conceptualisation of project management, and leadership and why they are important in engineering education context, can be captured in three questions:

- *What is project management?* Project management means to apply processes, methods, skills, knowledge, and experience to achieve specific project objectives according to the project acceptance criteria within agreed parameters (Association for Project Management, 2024).
- *What is leadership?* Leadership means creating the environmental conditions conducive to good performance: support of shared understanding, innovation, problem solving, resilience, and learning (Technical Leadership in Systems Engineering - SEBoK, 2024).
- *Why are they important in engineering?* Project management provides the tools and structures needed to plan and deliver outcomes, while leadership ensures direction, alignment, and innovation in complex and interdisciplinary contexts. Together, they enable engineers to collaborate effectively and respond to societal and technological change.

How PBL supports project management and leadership

In a PBL context, project management and leadership are developed through the project and teamwork dimensions. Students plan and deliver semester-long projects, negotiate roles, and share responsibility for outcomes. Leadership here is typically informal, with practices such as shared leadership (distributed responsibilities across the team) (Carson et al., 2007), emergent leadership (individuals stepping up when needed) (Davis & Eisenhardt, 2011), and rotating leadership (leadership positions changing over time) (Hanna et al., 2021).

As problems and organizational contexts become more complex — e.g., interdisciplinary collaboration or multi-team systems — the demand for explicit project management increases, while leadership is needed to provide direction, alignment, and motivation (Kolmos et al., 2024; Lindvig et al., 2017). Developing project management and leadership competencies in PBL does not happen automatically; it requires explicit opportunities for practice, reflection, and feedback. The guide below summarises what students can gain through project work and what educators should consider when supporting the development of these competencies (Table 4.2.5).

Table 4.2.5: Educator guide: fostering project management and leadership in PBL

<i>What students gain through PBL</i>	<i>What educators need to ensure</i>
Understand differences and dependencies between project management and leadership	Make learning outcomes, activities, and assessments explicitly target both competencies (constructive alignment)
Practice planning, monitoring, and delivering projects in disciplinary and interdisciplinary teams	Provide space and tools for students to experiment with project structures and roles
Experience informal leadership through shared, emergent, and rotating roles	Support student-centred learning and create opportunities for leadership to emerge naturally
Learn to navigate multi-team and interdisciplinary contexts	Scaffold collaboration across disciplines and teams; help students reflect on leadership practices

Practitioner takeaway

For engineering educators, the key is not to treat project management and leadership as tacit or implicit outcomes. Instead, they should be explicitly embedded in curricula, supported by constructive alignment, practical opportunities for role-taking, and space for reflection. This helps students carry forward both competencies into their professional lives.

2.3 Collaboration and co-creation

Why do they matter?

At PBL-based institutions like AAU, where projects are team-based, collaboration and co-creation are essential transferable competencies. They enable students to share and build ideas, supporting problem solving and innovation, but depend on psychological safety. Their meaning and importance in engineering education can be summarized as follows.

- *What is collaboration?* Collaboration can be defined as a joint effort by multiple people towards a group goal (Briggs et al., 2006). It requires abilities like working productively with others toward shared goals, communication, coordination, and conflict resolution (Marks et al., 2001).

- *What is co-creation?* Co-creation goes beyond collaboration by generating new knowledge or solutions together, requiring creativity, shared ownership, and openness to diverse perspectives.
- *Why important in engineering?* Collaboration and co-creation are essential for addressing complex, interdisciplinary challenges, while fostering creativity, innovation, and mutual learning — skills highly valued across engineering sectors.

Psychological safety and well-being as foundations for collaboration and co-creation

Psychological safety refers to a climate where individuals feel safe to take interpersonal risks when voicing ideas, asking questions, or admitting mistakes, without fear of judgement (Edmondson, 1999; Kahn, 1990). Research shows that psychological safety enhances open communication, trust, and creativity in teams (Edmondson & Mogelof, 2005; Han et al., 2019). In PBL, psychological safety closely links to academic well-being, which includes both emotional aspects (enjoyment, low stress) and cognitive-behavioural aspects (engagement, a sense of accomplishment). Well-being is shaped by students' self-efficacy and autonomy as well as by how supportive the learning environment is (Chen et al., 2023a; Clausen et al., 2025). Educators therefore play a central role in cultivating environments where collaboration and creativity can flourish, through practices like establish shared norms early in a project (e.g., *'no question is stupid'*, and mistakes as learning opportunities; set learning goals for their collaboration skills and reflect on their progress; and create spaces for creative collaboration, open communication, and trust-building (Hansen et al., 2025; Hansen & Christensen, 2025). Such practices encourage academic agency — students' belief that their efforts can influence learning outcomes — which is associated with greater well-being (Chen et al., 2024).

Role of facilitators and educators

Facilitators are central to shaping psychological safety and collaborative culture. Key strategies include early check-ins to monitor team dynamics and address conflicts, and structured scaffolding — particularly in the first year — through initiatives such as AAU's introductory PBL module on project management, teamwork, and conflict resolution (Du et al., 2020). Clear milestones help prevent last-minute crises, while constructive feedback and role modelling signal that students' progress is valued. These practices emphasise that collaboration and co-creation do not emerge automatically but require intentional support and scaffolding. The following guide summarises what students can gain through PBL teamwork and what educators should consider when creating the conditions for effective collaboration and co-creation (Table 4.2.6).

Table 4.2.6: Educator guide: supporting collaboration and co-creation in PBL

<i>What students gain through PBL</i>	<i>What educators need to ensure</i>
Learn to voice, share, and build ideas in teams	Create psychologically safe climates where all contributions are valued
Develop creativity and ownership through co-creation	Scaffold collaboration with clear structures and norms, especially in early semesters
Strengthen academic well-being and agency	Monitor team functioning with regular check-ins; provide timely feedback
Build long-term collaboration competencies (communication, trust, conflict resolution)	Align learning outcomes and assessments with collaborative skills, not only technical outputs

Practitioner takeaway

For educators, fostering collaboration and co-creation also involves supporting students' well-being. By developing teamwork norms, scaffolding early collaboration, role modelling, and constructive feedback, educators help students build confidence and creativity. Methods for creative teamwork can support this process. Without such support, collaboration may remain superficial; with it, students gain lasting professional competencies.

Complex problem solving, project management, collaboration, and co-creation form the core transferable skills in PBL. However, contemporary engineering also requires students to extend beyond these foundations — particularly through interdisciplinarity and the capacity to negotiate professional identity and exercise agency. The following sections show how these dimensions deepen and expand competency development within PBL.

2.4 Interdisciplinarity

Why does it matter?

Complex societal problems — such as sustainability transitions, digitalisation, and global health — are rarely confined to a single discipline. Addressing these challenges requires interdisciplinary collaboration, where knowledge, perspectives, and methods from different fields are integrated (Fortuin et al., 2023; Klein, 2018; van den Beemt et al., 2020). In engineering education, interdisciplinarity resonates closely with teamwork and collaboration but goes beyond them by explicitly requiring students to cross disciplinary boundaries and reflect on their own and others' contributions. Interdisciplinary and its importance in an engineering context can be summarized as follows.

- *What is interdisciplinarity?* Interdisciplinarity involves combining insights, methods, or approaches from two or more disciplines to address complex problems (Keestra & Menken, 2016; Klein, 2018). It ranges from narrow forms, involving closely related fields such as different branches of engineering, to broad forms that bridge more distant disciplines, such as engineering and the social sciences or humanities.
- *Why is it important in engineering?* It enables students to engage with ill-defined problems that require multiple perspectives. It supports the development of key competencies such as boundary crossing, coordination, reflexivity, and co-enactment, and prepares graduates to work effectively in multidisciplinary and cross-sectoral professional environments.

Challenges in interdisciplinary learning

Students often struggle with interdisciplinarity due to cognitive obstacles (e.g., conflicting disciplinary practices, different epistemic values) as well as institutional barriers (MacLeod, 2016). Research carried out at AAU shows that students working with broad interdisciplinarity frequently find it difficult to establish a common project focus, create interdependencies, or align disciplinary contributions (Routhe et al., 2021; Routhe et al., 2022). Without clear goals and facilitation, interdisciplinary learning risks remaining tacit and superficial.

How PBL supports interdisciplinarity

In a systemic PBL environment, problems are the point of departure, supporting both disciplinary and interdisciplinary competency development (Holgaard & Kolmos, 2019; Kolmos et al., 2024). Interdisciplinary competencies are fostered when students work with authentic, complex problems requiring input from multiple fields; reflect on how their disciplinary knowledge interacts with that of others; and engage in constellations where teams from different programmes collaborate on shared challenges.

At AAU, interdisciplinarity ranges from students borrowing perspectives from neighbouring disciplines to multi-team projects that span engineering, social sciences, and humanities. Examples include 'system projects' where teams from different engineering programmes collaborate on a shared theme such as sustainable mobility. Benefits include exposure to multiple perspectives on complex problems; opportunities for interdisciplinary project management and leadership; and reflection on the value and limitations of one's own disciplinary contributions.

These benefits, however, depend on intentional design and support. The following guide summarises what students gain through interdisciplinary PBL work and what educators need to ensure (Table 4.2.7).

Table 4.2.7: Educator guide: supporting interdisciplinarity in PBL

<i>What students gain through PBL</i>	<i>What educators need to ensure</i>
Collaborate across disciplines and perspectives	Set a clear vision and purpose for interdisciplinary learning
Manage interdisciplinary projects and leadership roles	Constructively align learning outcomes, activities, and assessments
Reflect on their own and others' disciplinary contributions	Co-construct boundary objects (e.g., societal challenge or shared artefact) to anchor collaboration
Develop boundary-crossing skills (coordination, reflexivity, co-enactment)	Scaffold team building across disciplines; provide facilitation focused on collaboration and leadership

Practitioner takeaway

For educators, interdisciplinarity should not be treated as an implicit outcome of teamwork. It needs to be explicitly embedded through aligned outcomes, interdisciplinary project design, and facilitation. Providing boundary objects, fostering common ground, and scaffolding cross-disciplinary collaboration helps students develop the competencies required for interdisciplinary professional contexts.

2.5 Professional identity and agency

Why do they matter?

Becoming an engineer involves more than acquiring technical knowledge. It also requires students to see themselves as future professionals and to act with confidence and purpose in shaping their learning journeys. Professional identity and learner agency are therefore intertwined transferable competencies that influence students' motivation, persistence, and capacity to adapt across academic and professional transitions. The meaning of professional identity and learner agency and their importance in an engineering context is summarized below.

- *What is professional identity?* Professional identity refers to how students see themselves as engineers-in-the-making, shaped by their motivations, beliefs, competencies, and recognition from communities of practice (Chen et al., 2022, 2023b). It is strengthened through engagement in authentic engineering tasks and validation from peers, educators, and external stakeholders.
- *What is learner agency?* Learner agency is the capacity and willingness to take purposeful action, such as setting goals, self-regulation, collaboration, and making decisions to shape one's learning. It emerges dynamically through students' interactions with curricular, social, and professional contexts (Du et al., 2022; Jiang et al., 2023).
- *Why is it important in engineering?* Professional identity motivates students to persist and find meaning in their learning, while agency enables them to act on this motivation, adapt to challenges, and contribute actively to collaborative

and professional contexts. Together, they prepare students not only to become engineers but to act as engineers.

How PBL fosters identity and agency

Research shows that PBL provides a powerful context for fostering both professional identity and learner agency. Identity develops through real-world, semester-long projects with stakeholder interaction, in which students internalise what it means to be an engineer, reinforced by recognition from others (Chen et al., 2022; 2023b). Agency develops by defining problems, setting goals, organising roles, and reflecting, through which students practise self-regulation and decision making (Du et al., 2022; Jiang et al., 2023). Mutual reinforcement occurs when identity strengthens motivation to act, while agency reinforces identity, especially through authentic project contexts (Guerra et al., 2022, 2025).

Despite these benefits, fostering identity and agency is not straightforward. Many students rely heavily on instructor guidance rather than engaging in self-directed learning, and while they may articulate their learning, they often struggle to translate it into professional action or sustained identity development. This development also varies across cultural, curricular, and disciplinary contexts, requiring context-sensitive approaches. Moreover, motivation may remain individual and passive if broader institutional or social factors are not addressed (Du et al., 2022; Chen et al., 2023a).

These insights highlight the need for intentional design and support. The following guide summarises what students gain through PBL experiences and what educators need to ensure to strengthen identity and agency (Table 4.2.8).

Table 4.2.8: Educator guide: supporting professional identity and agency in PBL

<i>What students gain through PBL</i>	<i>What educators need to ensure</i>
Develop a sense of 'becoming an engineer' through authentic practice	Design authentic, practice-oriented projects connected to real engineering challenges and external stakeholders
Learn to set goals, plan, monitor, and reflect on their learning	Balance scaffolding with autonomy; teach reflective practices for self-regulation
Experience progressive growth across the curriculum (from novice to advanced)	Embed progression: from first-year introductory projects to advanced capstones, with increasing independence
Connect their efforts to societal and professional contexts	Strengthening industry and community links through cooperative projects, internships, and showcase events

Practitioner takeaway

Supporting professional identity and learner agency requires more than granting students freedom. It involves authentic, progressive, and reflective PBL experiences where students are treated as engineers-in-the-making and equipped to act with agency. By balancing scaffolding and autonomy and linking projects to real-world contexts, educators help students actively develop into adaptable professionals.

Together, the eight competencies — complex problem solving, project management, leadership, collaboration, co-creation, interdisciplinarity, professional identity, and professional agency — demonstrate how transferable skills are systematically cultivated in PBL. While distinct, they are deeply interconnected and mutually reinforcing across problems, projects, and teamwork. This highlights the need for integrated, progressive learning designs in which such skills are made explicit, scaffolded, and constructively aligned.

3 Recommendations

Our recommendations draw on decades of research on systemic PBL at AAU while integrating students' insights. From a student perspective, engagement increases when projects have clear real-world relevance. Students value structured guidance in the first year, combined with greater autonomy in later stages. Many find it difficult to articulate their competencies unless reflection and assessment make them explicit. They also emphasise the importance of psychological safety, noting that feeling safe to contribute is essential for meaningful and effective collaboration. The aim of these recommendations is to provide clear, actionable guidance for embedding transferable competencies in engineering education.

3.1 Practical recommendations

Make transferable competencies explicit by clearly defining them in learning outcomes, teaching activities, and assessment criteria. In practice, this involves designing curricula where these competencies are not implicit but deliberately articulated and assessed. The rationale for this approach is that students often perceive transferable skills as 'hidden' unless they are explicitly taught and evaluated (Routhe et al., 2023).

Integrate competencies systemically by embedding skill development across the curriculum through repeated cycles of problem solving, project work, and teamwork. This ensures that students encounter and apply these competencies in multiple contexts over time. Evidence suggests that students are more likely to recognize and value competencies when they have multiple opportunities to practice them (Lindsay et al., 2024).

Balance scaffolding with autonomy by providing strong guidance in early semesters — such as through introductory modules and structured teamwork norms — and then gradually reducing support as students' progress. This staged approach helps students build confidence and foundational skills before taking on more independent and complex tasks. Research shows that early scaffolding enhances students' confidence

and well-being, while more advanced, autonomous projects foster a sense of agency (Du et al., 2020; Chen et al., 2023).

Connect learning to real-world contexts by using authentic, interdisciplinary problems, ideally in collaboration with external stakeholders. This approach helps students see the relevance of their learning and apply their skills in meaningful ways. Recognition and feedback from professionals further strengthen students' sense of identity and motivation (Chen et al., 2022).

Foster psychological safety and well-being by creating learning environments where students feel comfortable taking risks, expressing ideas, and learning from mistakes. Such environments encourage deeper engagement and collaboration. Research indicates that psychological safety is strongly correlated with improved collaboration, creativity, and overall well-being (Clausen et al., 2025). For an overview of practical recommendations, see Table 4.2.9.

Table 4.2.9: Practical recommendations

<i>Do's</i>	<i>Don'ts</i>
Design authentic problems that connect to societal challenges	Assume competencies will 'just emerge' through team projects. Without explicit design, transferable skills remain underdeveloped
Use boundary objects (shared artefacts, project themes) to support interdisciplinarity	Overload students with unstructured PBL early on; this risks stress and disengagement
Provide structured opportunities for reflection on collaboration, leadership, and identity	Treat project management and leadership as implicit roles and make them invisible in the curriculum structures like expected learning outcomes.
Offer progressive exposure to interdisciplinary and multi-team settings	Neglect staff development — educators need training to act as facilitators, not only as disciplinary experts

3.2 Lessons learned, attention points, and adaptability

One important learning lesson is that identity and agency develop gradually over time, as students often require external recognition and exposure to role models before they begin to see themselves as engineers. Interdisciplinary learning, while valuable, presents challenges because it involves navigating different paradigms; this makes structured scaffolding and clearly defined goals essential. Shared leadership has proven to be effective, particularly when roles are rotated, as this fosters a sense of authentic responsibility among students. Additionally, reflection plays a critical role in learning, with activities such as journals and feedback helping to strengthen students' metacognitive skills.

Institutional alignment is an important attention point, requiring that problem-based learning (PBL) competencies are embedded within broader educational frameworks such as the NQF or EQF. Equally important is ensuring progression, where competency development is staged across semesters with increasing levels of autonomy and complexity. Sensitivity to context is also necessary, as approaches must be adapted to reflect cultural and disciplinary differences. Finally, attention must be given to staff roles, ensuring clarity and appropriate support for educators who balance responsibilities as researchers, lecturers, and facilitators.

The effectiveness of these approaches depends on ability to adapt to local conditions and contextual factors such as class size, resources, and institutional culture. Smaller classes tend to support emergent leadership, whereas larger cohorts require more structured approaches and additional scaffolding. Even in settings with limited resources, transferable competencies can still be cultivated through well-designed problems and reflective activities. In institutions with less experience in PBL, it is advisable to begin with pilot projects and gradually scale up implementation as capacity and confidence grow.

3.3 Continuous improvement

To ensure students develop relevant and transferable competencies and skills, continuous improvement must be embedded in both curriculum design and teaching practice. Educators can:

- Use self-assessment tools to support students to track their skill development over time and create their own competencies profile;
- Gather feedback from students and external partners to evaluate how well projects support competency development;
- Share best practices and case examples among faculty through professional learning communities;
- Regularly revise curricula to align with emerging societal and industry needs.

These strategies are exemplified in several initiatives at AAU:

- *Introductory PBL module.* First-year students learn project management, collaboration norms, and conflict resolution in a scaffolded setting;
- *System projects.* Interdisciplinary, multi-team projects address sustainability challenges such as mobility and energy transition;
- *Project expos.* Students present their work to external stakeholders, strengthening identity and motivation through recognition;
- *Progression through tailor-made workshops.* After the first year, tailor-made workshops are introduced, addressing specific transferable skills to support students' progression in PBL competencies throughout the course of their studies;
- *Competency profiles.* Over 1,000 student profiles have been analysed to identify strengths and gaps, directly informing curriculum redesign.

Intentional support and continuous feedback loops help ensure that collaboration and co-creation are not superficial but become deeply embedded competencies which students carry into professional practice.

Practitioner takeaway

Embedding transferable skills in engineering education requires a systems approach, with explicit, progressive, authentic, and reflective learning opportunities across the curriculum. By aligning problems, projects, and teamwork with constructive outcomes, educators can ensure that students not only develop disciplinary expertise but also the transferable skills needed to thrive as engineers in complex and changing worlds.

4 Concluding reflections

This chapter has illustrated how a systems approach to PBL provides the conditions for developing transferable skills throughout engineering education. By focusing on key competency areas, such as complex problem solving, project management, leadership, collaboration, co-creation, interdisciplinarity, professional identity, and professional agency, we have shown how competencies are interdependent and reinforced through authentic problems, project work, and teamwork. For educators, the main message is that transferable competencies must be intentional, explicit, and progressively scaffolded, as they do not emerge automatically. For institutions and researchers, our decades of work at AAU demonstrate the importance of a long-term, research-based approach to understand competency development through PBL that continuously integrates the perspectives of students, educators, and leaders to sustain and evolve systemic PBL practices. A research-based approach extends beyond evidence-informed educational practice by recognizing the role of research in generating robust evidence and scientific knowledge to understand, inform, and advance engineering education. By integrating educational theories with rigorous research methodologies, it strengthens research and development efforts and supports the continuous improvement of practice in response to professional needs and societal challenges.

We hope that the following further reading and resources, which illustrate how AAU's PBL approach develops transferable skills, can be of inspiration for other practitioners in strengthening their pedagogical competence to integrate these skills explicitly into teaching and learning practices. For PBL competences and competence profile, see UCPBL. (n.d.-b, n.d.-c) and for problems in PBL, see UCPBL (n.d.-d). For all systems projects related background, see Aalborg University (n.d.-a, n.d.-b, n.d.-c) and for collaboration and co-creation Hansen and Christensen (2025). Finally for facilitation of learning, we recommend Du et al. (2025) and Kolmos et al. (2008) as well as UCPBL (n.d.-a).

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AI statement

During the preparation of this work, the authors used Microsoft Co-pilot in order to reduce the wordcount where appropriate and proofread the chapter. After using this tool, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

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4.3

Teaching and Learning Professional Competencies through an Integrated Learning Path in the Faculty of Engineering Technology at KU Leuven

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This chapter presents the design and implementation of an integrated learning path for professional competencies within the engineering technology curriculum at KU Leuven. Responding to industry expectations and educational reforms, the Faculty of Engineering Technology introduced a holistic approach that embeds six clusters of professional competencies — team dynamics, project management, professional communication, innovation and creativity, entrepreneurship, and ethics and society — throughout the bachelor programme. Rather than treating these competencies as add-ons, they are interwoven into authentic engineering experiences that increase in complexity and openness over time, supported by just-in-time seminars, coaching, and structured feedback. Professional engineering identity development serves as the guiding principle of the learning path, fostering students' awareness of their future roles and talents while strengthening self-reflection and lifelong learning attitudes. Tools such as an e-portfolio and targeted reflection activities support this process. The chapter illustrates the approach through inspirational cases and discusses lessons learned from the multicampus implementation. Student perception data and longitudinal monitoring reveal successes, challenges, and areas for improvement. The contribution concludes with recommendations for sustaining competency development and identity formation across bachelor programmes, offering insights for engineering educators and curriculum designers aiming to integrate transferable skills into engineering curricula.

1 Changing landscape in education and industry

The engineering profession is undergoing a profound transformation, driven by rapid technological advancements, shifting societal expectations, and evolving labour market demands. In response, engineering education institutions are shifting toward competency-based curricula that prepare graduates not only with strong technical expertise but also with the professional competencies needed to thrive in complex, interdisciplinary, and ethically charged environments. This chapter presents how such a shift has been realised at KU Leuven (Belgium) at the Faculty of Engineering Technology (FET) through the development of an integrated learning path for professional competencies.

1.1 Industry need for professional competencies

The need to foreground these competencies is echoed in both national and international labour market reports. Professional competencies are defined as the non-technical knowledge, skills, and attitudes required for effective engineering practice, including for example teamwork, communication, project management, innovation, and ethical awareness (Craps et al., 2021).

A KU Leuven study (2016) found that while employers are generally satisfied with the technical knowledge of engineering graduates, they consistently call for stronger development of professional competencies. Similarly, the World Economic Forum (2020) highlights the growing importance of competencies such as active learning, resilience, stress tolerance, and flexibility — skills that are increasingly essential in a rapidly changing world of work.

These insights underscored the need for FET to design a more structured approach to the development of professional competencies, leading to the creation of an integrated learning path — i.e., the way in which the learning is organised — (Codex Hoger Onderwijs, 2014) embedded across the bachelor curriculum.

1.2 Educational need for a coherent approach – institutional context

In Belgium, specifically in Flanders, higher-education quality assurance has evolved into a model centred on institutional responsibility. Since 2019, quality is monitored through a two-step process: internal quality assurance by the institution and institutional review by the Accreditation Organisation of the Netherlands and Flanders (NVAO). Unlike systems in countries like Ireland, Australia, or the United States, Flemish engineering programmes do not work with externally imposed discipline-specific or generic learning outcomes. Instead, institutions align with the European Qualifications Framework (EQF) (Europass, n.d.) and develop their own programme-specific learning outcomes in line with the agreements among engineering faculties in Flanders. This autonomy allows faculties to design curricula that reflect institutional vision and regional industry needs. At FET, this has led to the development of 21 programme-specific learning outcomes.

With more than 60,000 students and a strong international reputation for innovation, KU Leuven is the largest university in Flanders. It is a comprehensive, research-

intensive university with programmes offered across multiple campuses. FET is one of the youngest faculties, with today over 6,000 students enrolled in engineering technology programmes across ten disciplines: agricultural and horticultural engineering, biochemical engineering, civil engineering, chemical engineering, electromechanical engineering, electronics and ICT engineering, energy engineering, food industry engineering, computer science engineering, and nuclear engineering. The faculty was established in 2013 following a merger of engineering departments from six different University Colleges of Applied Sciences. This diversity — across programmes, traditions, and regional contexts — meant that earlier implementations of professional competencies varied significantly. Some competencies were addressed implicitly or in isolated learning activities, and reflection and feedback practices differed. Students reported difficulties in linking these competencies to engineering practice or to their future engineering roles, highlighting the need for a coherent, longitudinal learning path.

This dual pressure — from industry and educational reform — created momentum for a faculty-wide curriculum redesign. In 2017, the faculty initiated the preparation of this major curriculum reform and first implementation started in 2020. One of the significant outcomes was the structural implementation of a learning path for professional competencies, ensuring that their development is intentional, progressive, and visible to students (Langie et al., 2022). Rather than treating these skills as add-ons, they are now integrated into authentic engineering tasks and assessed in ways that make their relevance tangible to students. The integrated learning path aims to support students in developing a robust professional engineering identity and a clearer understanding of their future professional roles. This approach not only aligns with the broader goals of the European Higher Education Area but also with KU Leuven's educational vision on supporting students' disciplinary future self (KU Leuven, n.d.-a).

In the following paragraphs we describe the holistic approach and the design of the learning path within the bachelor programme, concluding with critical reflections and practical recommendations.

2 Holistic approach in competency development

To ensure that students do not perceive professional competencies as add-ons but as integral to their identity as engineers, the bachelor curriculum adopts a holistic didactic approach that intentionally integrates disciplinary knowledge, practical skills, and professional attitudes. This approach positions experiential learning as a central lever for competency development and builds on well-established pedagogical frameworks on engineering education such as project-based learning and problem-based learning (Conger et al., 2010; Duderstadt, 2008; Graham, 2018; Woodcock et al., 2021).

2.1 Why experiential learning is central

Experiential learning emphasises that meaningful development occurs when students engage in authentic and complex situations (Chickering, 1976; Itin, 1999). In engineering education, such situations can include internships, multidisciplinary

projects, laboratory work, community-based projects, fieldwork, and interactive simulations or games. These learning experiences differ from traditional instruction: students interact with others (peers, clients, or stakeholders) rather than in isolation, and solve concrete, real-world problems rather than engage solely with textbooks. They apply and integrate technical knowledge with professional competencies — such as communication, teamwork, or ethical reasoning — in ways that mirror real engineering practice.

These authentic contexts allow students to experience competency development as interconnected and meaningful. For example, a communication module may introduce principles of target-group communication, but it is within an Engineering Experience project that students discover their relevance when reconciling divergent team expectations (team dynamics), coordinating deadlines (project management), or debating societal implications of the proposed solution (ethics).

Experiential learning also supports students in exploring key identity-related questions: Who am I as an engineer? Which roles align with my interests and strengths? How do my competencies shape the kind of engineer I am becoming? Employers note that engineering graduates may enter the workforce with unrealistic or incomplete understanding of actual engineering roles. By engaging students' whole identity — intellectual, social, ethical, and affective — experiential learning enables them to align educational choices with their emerging professional aspirations (Craps et al., 2020).

2.2 Four pillars structuring the bachelor programme

The educational approach is reflected in the structure of the new bachelor programme. The programme is organised around four mutually reinforcing pillars (Fig. 4.3.1):

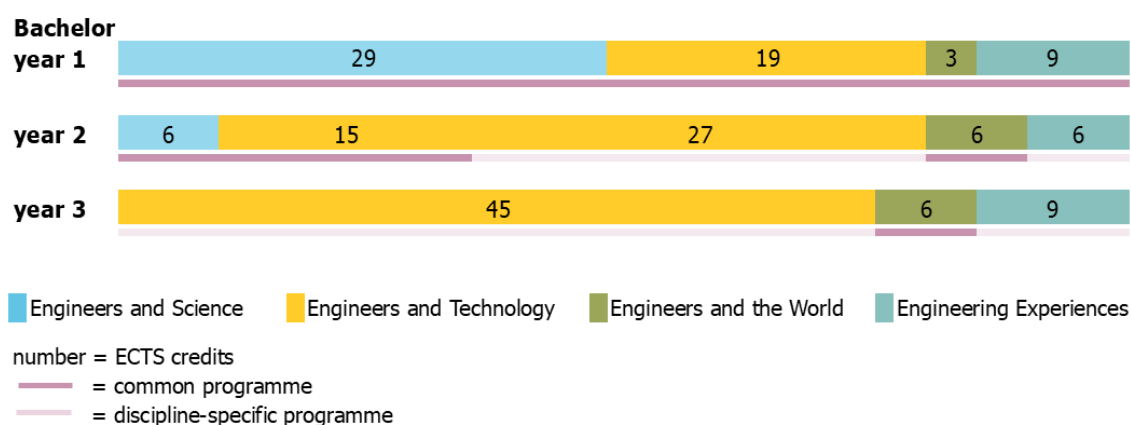


Figure 4.3.1: The four pillars of the KU Leuven bachelor programme in Engineering Technology. Own Work. Licensed under CC-BY 4.0.

1. Engineering and Science provides the multidisciplinary scientific foundations. Example modules are Fundamentals of Mathematics, Dynamics and Energy, and Computational Thinking.

2. Engineering and Technology deepens discipline-specific technological knowledge and skills. Example first-year modules are Biotechnology, Statics and Strength of Materials, and Thermal-Fluid Sciences.
3. Engineering and the World situates engineering in societal, ethical, and economic contexts, while supporting personal development and lifelong learning. Example modules are Enterprises and Ethics, Engineering and Economics, and Engineering and Sustainability.
4. Engineering Experiences offers authentic projects and challenges that allow students to integrate knowledge, skills, and attitudes, and to discover their talents as future engineers.

The learning path for professional competencies is structurally embedded across pillars 3 and 4. In the first year, students follow a common programme that lays the scientific and technological foundation. In later years, the programme gradually becomes more discipline-specific. Depending on the discipline, students can select different options or focus areas within their major. However, the learning path for professional competencies continues across all majors and specializations.

3 The learning path for professional competencies

The integrated learning path for professional competencies structures how students encounter, experience, and reflect on six competency clusters throughout the bachelor programme. This section outlines the components, identity-building elements, implementation principles, and structural embedding of the learning path across the multicampus FET.

3.1 Six competency clusters of the learning path

The learning path is structured around six competency clusters, selected based on institutional priorities, feedback from industry, and educational research (KU Leuven, n.d.-b):

- Team Dynamics refers to the dynamics within a team that support effective collaboration and the achievement of shared goals.
- Project Management focuses on planning and managing projects, including deadlines, risk analysis, adjustments, and the use of planning tools.
- Professional Communication is about communicating effectively with different target audiences, both orally and in writing, using different media and in different contexts.
- Innovation and Creativity ranges from idea generation to prototype development in assignments that evolve from relatively structured to fully open formats, often involving external stakeholders.
- Entrepreneurship covers competencies ranging from understanding business fundamentals (e.g., annual accounts or investment proposals) to identifying opportunities and developing ventures.
- Ethics and Society addresses responsible and ethical behaviour as an engineer, including sustainable design and development.

These clusters develop iteratively throughout the bachelor programme and are reinforced through both dedicated modules and pillar 4, Engineering Experiences (see Section 2.2). Students encounter them in seminars, apply them in authentic tasks, and reflect on their development over time.

3.2 Engineering identity as guiding thread

A key aim of the learning path is to support students in developing a clearer sense of their emerging engineering identity. Through authentic engineering experiences that increase in openness and complexity, students explore their talents, preferences, and potential future roles.

Professional competencies are therefore not presented as abstract expectations but as integral elements of professional engineering practice. This explicit connection between action and reflection helps students understand why these competencies matter and how they shape the kind of engineer they are becoming.

To facilitate this process, we embedded several instruments that support identity development and competency growth. For example, the e-portfolio allows students to document their learning, set goals, track progress, and reflect on their development across the programme (Dujardin et al., 2024). Example 1 illustrates this process in more detail.

In addition, the PREFER tools (Professional Roles and Employability for Future EngineerRs) provide students with validated insights into early-career engineering roles, the competencies associated with these roles, and their own preferences and talents (Craps et al., 2021; Langie & Craps, 2020). The tools include (1) a competency-based framework describing three typical engineering roles for early career engineers; (2) a personal preference test that helps students explore which roles align with their motivations; and (3) a situational judgement test that offers feedback on role alignment and competency strengths. By linking these insights to engineering experiences, students can better recognise which competencies are important for the roles they aspire to and identify areas for further development.

Although this chapter focuses on the bachelor programme, this trajectory continues in the master programme through elective modules, internships, and advanced projects. Identity development and competency growth thus form a coherent learning path from the first year to graduation.

Example 1. Integrating projects, competencies and identity development through the e-portfolio

The e-portfolio is structured around a Personal Development Process (PDP), with five iterative steps: identifying competency gaps, setting goals, acting on a learning plan, monitoring progress, and reflecting on future needs (Dujardin et al., 2024). This process is embedded in pillar 4, Engineering Experiences, where students receive seminars on professional competencies and apply these directly in the project work.

Each semester, students individually engage in reflection activities such as:

- *Self-assessment on a series of professional competencies (e.g., teamwork, communication, ethical thinking, perseverance);*
- *Setting and planning concrete actions for improvement of a self-selected competency;*
- *Monitoring actions and documenting progress;*
- *Reflecting on feedback from coaches (three times per semester);*
- *Linking competencies to engineering practice and personal aspirations, strengthening the connection between academic work and future professional roles.*

The PREFER tools (PREFER, n.d.) are integrated into the portfolio to connect competency development to professional roles, reinforcing the link between professional engineering identity and practice. Each semester, students receive feedback on their reflection on self-assessment and action plan, monitoring, and takeaways.

The e-portfolio is embedded in Blackboard Ultra, KU Leuven's digital learning environment. Students can actively steer and monitor their learning process and that of their peers through online tests, discussion forums, e-portfolios, etc. Participation in the e-portfolio is part of the final evaluation of the Engineering Experiences modules.

3.3 Structured growth through the sub-learning paths

The curriculum reform was a collaborative effort involving multiple expert teams. Each team was tasked with designing a learning path for a specific knowledge domain or competency cluster, ensuring a coherent trajectory from the start to the end of the bachelor programme. Hence, each competency cluster was translated into a sub-learning path outlining how students encounter, practise, and deepen the competency across the curriculum. These sub-learning paths are:

- clarify expected progression across years;
- support alignment between campuses;
- guide educators in planning and coaching;
- help students understand how competencies evolve over time.

A sub-learning path includes seminars, authentic tasks, feedback loops, and reflection activities. Example 2 illustrates how this works for the competency professional communication.

Example 2. Building a sub-learning path Professional Communication that goes beyond writing and presentation skills

The sub-learning path Professional Communication creates the opportunity to practice the classical skills such as writing and presentation skills, but also other essential competencies. Every year, it offers students strategic communication skills and feedback literacy skills. In the first bachelor year, students learn the foundations

of effective communication tailored to target audiences. In Year 2, the focus shifts to connective communication within teams and with external stakeholders, such as clients. In the third year, students develop persuasive communication skills.

Students are introduced to core communication principles and tools, supported by a guidebook summarizing the theory, principles, and faculty agreements (use of British English spelling, IEEE or APA reference style, report templates, etc.) which they use throughout the programme. Students progressively develop genre-specific skills, such as presentation skills (Year 1), visualisation skills (Year 2) and scientific reasoning skills (Year 3).

In the master programme, the learning path of the bachelor programme continues with a series of elective modules, such as sales techniques, intercultural communication, principled negotiation, and interpersonal coaching, allowing for further specialisation.

3.4 Principles guiding implementation in practice

The implementation of the learning path follows a modular structure grounded in three key pedagogical principles. These principles ensure that the competency clusters and sub-learning paths are enacted meaningfully and consistently across modules and projects.

1. *Just-in-time seminars* introduce relevant competencies when students need them for specific tasks or projects. This ensures that theoretical input is applied immediately, which increases its perceived relevance.
2. *Training moments in authentic tasks* allow students to apply competencies within discipline-specific and interdisciplinary engineering contexts. These experiences help students to perceive competencies as interconnected and essential for engineering work.
3. *Assessment and feedback through coaching* provide iterative formative feedback rather than one-off evaluation. Students receive guidance on their progress, strengths, and development needs, supporting reflective practice and sustained growth.

Ongoing monitoring shows that coaching, interdisciplinary collaboration, and just-in-time instruction have proven essential for successful implementation (see Section 5).

3.5 Realising coherence across a multicampus faculty

FET is spread across several campuses, each with its own traditions, research expertise, and regional industry connections. The learning path ensures that:

- Intended learning outcomes remain aligned across campuses;
- Competency expectations are consistent;
- Students follow parallel developmental trajectories;
- Campuses can contextualise learning using local expertise and partnerships.

Given the different traditions regarding professional competencies across campuses and disciplines, the structured learning path provided essential guidance for campuses with fewer established practices in this domain. The implementation required more effort for some campuses than for others. We therefore adopted an iterative implementation process, allowing campuses to progressively integrate the learning path while building capacity and experience. This process is still ongoing.

This balance between alignment and contextualisation has been essential for implementation. It allows campuses to design innovative project themes while maintaining a shared competency framework across the faculty.

4 Inspirational cases

The following cases (Examples 3-5) illustrate how the learning path for professional competencies is implemented across our multicampus faculty. They show how shared principles are enacted in diverse contexts while maintaining alignment in intended learning outcomes.

Example 3. Variation in topics and challenges — from building glass houses to Rube Goldberg machines

In the first-year module Engineering Experience 1, students engage in open-ended projects that integrate technical and professional competencies. Although campuses use different project themes, all aim to achieve the same learning outcomes.

Project structure:

- *Duration: 12 weeks in the second semester of the first year.*
- *Students work in interdisciplinary teams (3-10 students depending on campus).*
- *Projects integrate the four main engineering disciplines (Electromechanics, (Bio)Chemical, Electronics-ICT, and Construction Engineering).*

Example themes:

- *Rube Goldberg Machine: students design a complex machine to move a golf ball that integrates mechanisms from mechanical, chemical, electronic, and civil engineering into a unified system.*
- *Greenhouse of the Future: students design a sustainable greenhouse prototype. Sub-teams focus on structural design, bioreactor systems, automation, and environmental sensing, requiring cross-team collaboration to integrate solutions.*

Professional competency integration:

- *Just-in-time seminars introduce teamwork, project management, and presentation skills.*
- *Coaching is provided by technical coaches for discipline-specific support, and by professional competency coaches for team dynamics, planning, and communication.*
- *Assessment includes progress presentations and peer feedback, with increasing autonomy across the semester.*

Key takeaway:

Variation in themes stimulates creativity and local ownership, while shared learning outcomes ensure coherence in competency development across campuses.

Example 4. Creative Makers — an interdisciplinary experience that blends technology, design, and societal inquiry

This third-year project challenges students to design and build an indoor vertical farming setup, inspired by Dickson Despommier's concept (Platt, 2007), in collaboration with students from the faculty of Architecture and Visual Arts. The project highlights interdisciplinary collaboration and intertwined professional competencies.

Project structure:

- *Students work in specialized sub-teams (e.g., lighting, water systems, plant beds).*
- *The project spans two academic years, with iterative development across cohorts. Documentation is passed on to the next group.*
- *Rapid prototyping workshops initiate the project to stimulate creativity and experimentation.*

Professional competency integration:

- *Innovation and creativity are fostered through design constraints and time pressure.*
- *Project management is practiced through planning, coordination across sub-teams, and iterative development.*
- *Communication is critical in interdisciplinary settings. Students learn to adapt technical language for non-engineering peers.*
- *Visual communication is emphasized through sketches, photos, and concise documentation.*

Coaching format:

- *Two supervisors per team: one with technical expertise, and one with limited technical background, encouraging clear explanation.*

Teams use Discord for team coordination, revealing challenges in responsibility and internal communication. When such challenges arise, supervisors help students understand the potential consequences of their communication style in a professional setting and identify appropriate ways to address them. Key takeaway:

Interdisciplinary collaboration strengthens students' ability to articulate ideas, negotiate perspectives, and apply competencies in diverse professional contexts.

Example 5. Internal and external collaboration — partners in crime

This case illustrates collaboration with KU Leuven Libraries to integrate information literacy and AI literacy into the curriculum.

Project structure:

- *Information literacy is embedded in professional competency modules across the bachelor programmes.*
- *First-year students complete an online module followed by hands-on sessions in Engineering Experiences 1.*
- *Advanced sessions are tailored to discipline-specific needs.*

Professional competency integration:

- *Information literacy includes source evaluation, referencing, and ethical use of information.*
- *AI literacy supports students in critically assessing AI-generated content and in navigating digital ecosystems.*
- *Sessions are timed to align with academic writing sessions to enable direct application (e.g., research papers, technical reports).*

Collaboration format:

- *Library staff co-develop teaching materials and provide student sessions or online support.*
- *Coaching is provided by technical coaches for discipline-specific support and by professional competency coaches for writing skills and information literacy.*
- *External partners (e.g., industry professionals) may contribute real-world perspectives as a starting point for projects and information searches.*

Key takeaway:

These type of strategic partnerships by engaging relevant internal and external partners expand the learning path and ensure timely integration of emerging competencies.

5 Monitoring and evaluation

From the outset of the curriculum reform, systematic monitoring evaluated whether intended goals were achieved and identified areas for improvement. The monitoring strategy combined longitudinal student perception measurements with qualitative feedback from teaching staff and policy teams. This mixed-methods approach enabled the faculty to track changes over time and better understand how programme elements were experienced across campuses.

5.1 Monitoring approach

A longitudinal perception study, based on a questionnaire, was conducted among students in both the old and the new curriculum (KU Leuven Faculty of Engineering Technology, 2025). The study covered 16 themes — including professional

competencies, interaction with the labour market, practical experiences, societal relevance, interdisciplinarity, and lifelong learning — and used a six-point Likert scale. Data were gathered at multiple moments across the bachelor and master programmes (Fig. 4.3.2).

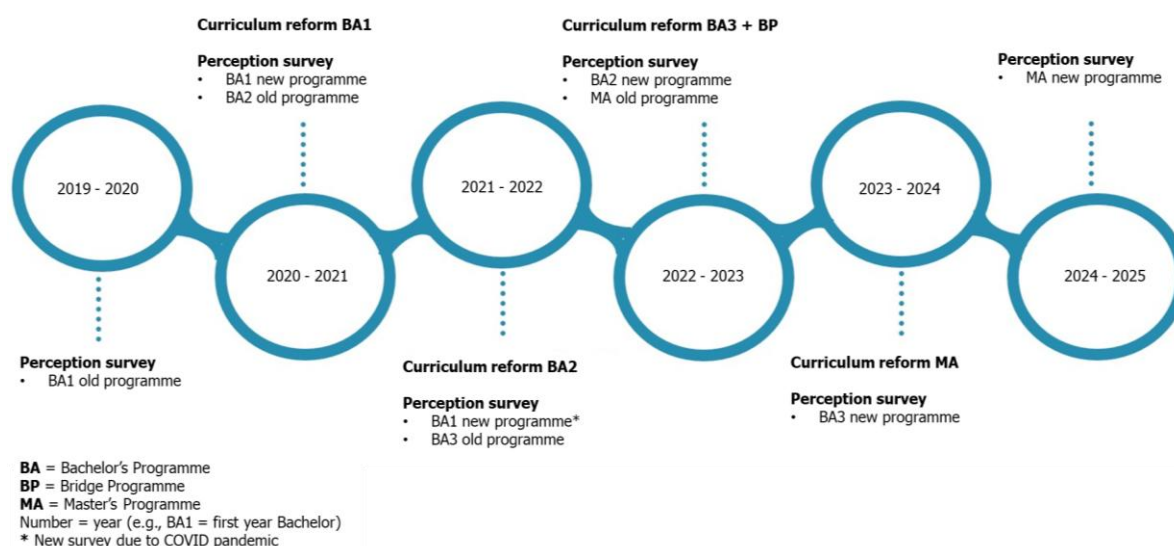


Figure 4.3.2: Timing of curriculum implementation and perception surveys. From Perceptiemeting Rapport by KU Leuven Faculty of Engineering Technology (2025). No further use allowed.

In 2019-2020, a baseline measurement was conducted in the old programme (first-year bachelor, BA1), followed by the first cohort in the new programme in 2020-2021 (Langie et al., 2022). Between 2022 and 2024, follow-up measurements tracked the developmental trajectory of subsequent cohorts. In total, 720 bachelor students participated in the old-programme survey (response rate 30%), while 516 students participated in the new-programme survey (response rate 28%) (KU Leuven Faculty of Engineering Technology, 2025).

This monitoring approach enabled the faculty to identify trends over time, compare cohorts, and inform programme adjustments at both faculty and campus level.

5.2 Student perceptions: what improved, what needs attention

The perception measurement for the theme professional competencies included four statements capturing students' experiences with communication, project management, business awareness, and the perceived relevance of professional competencies in engineering practice.

Table 4.3.1 presents the percentage of students that agree with the statement (score 4 or above) and the mean score. The results indicate that students in the new curriculum experienced stronger development of professional competencies. Two statements showed statistically significant improvement:

- Students more often indicated that they have trained specific communication skills (M = 4.08 vs. 4.27, $p < 0.05$; 70% vs. 77%);
- Students felt more encouraged to make progress in the field of project management (M = 3.98 vs. 4.16, $p < 0.05$; 66% vs. 76%).

Students in both programmes acknowledged the general importance of business knowledge and the usefulness of professional competencies for engineering practice.

Table 4.3.1: Students' perception of professional competencies in old and new bachelor programme (percentage agree and mean score with agree = Likert scale 4 (somewhat agree), 5 (agree) or 6 (strongly agree)).

	<i>BA old</i>	<i>BA new</i>	<i>p-value</i>
This year, I have trained certain communication skills.	70% (4.08)	77% (4.27)	<0.05
This year, I have learned that it is important for engineers to have knowledge of business (e.g. business models, financial aspects, etc.) in addition to technical expertise.	78% (4.35)	82% (4.41)	n.s.
This year, I was encouraged to make progress in the field of project management.	66% (3.98)	76% (4.16)	<0.05
This year has made me aware of the usefulness of professional competencies (e.g. communication, planning, meeting, leadership, etc.).	85% (4.58)	83% (4.50)	n.s.

A deeper analysis showed that Year 1 students in the new programme scored highest on awareness of the usefulness of professional competencies (M = 4.68, SD = 0.96), although scores declined slightly in later years (Year 2: M = 4.26; Year 3: M = 4.43). This pattern highlights the need for sustained visibility and reinforcement of competencies as students' progress into more discipline-specific phases.

Differences between campuses also emerged, which was expected given diverse traditions in professional competency development. Combining perception data with other themes (e.g., industry interaction, interdisciplinarity, societal relevance, and feedback) enabled more targeted programme optimisation across campuses.

5.3 Experiences and challenges in implementation

The implementation of the learning path has led to several successes but also revealed challenges that require continued attention. The following insights highlight what worked in practice and which issues required targeted interventions, offering you concrete takeaways.

Successes

One of the successes is that students, in particular in the first year, recognise the integration of professional competencies in authentic projects as relevant and valuable. In conversations, students report that professional competencies feel more meaningful when they are applied in engineering experiences rather than taught as isolated elements.

Second, professional engineering identity development is strengthened. Reflection tools and coaching support students in making sense of their developing competencies and future professional roles, especially in the early years when foundational modules may feel distant from engineering practice. Research showed that students' future-oriented perspectives influence how relevant and motivating they perceive their studies to be (Schepers et al., 2026). However, continued support is needed after the common first year, when students transition into discipline-specific majors.

Third, the curriculum reform fostered faculty-wide engagement and educational innovation through co-creation. The reform process was collaborative, involving teaching staff and experts across campuses and disciplines. This collaboration extended beyond formal meetings: educator teams jointly redesigned modules, shared teaching materials and practices, and experimented with on-campus and hybrid formats. Educator teams can apply for small-scale funding, e.g., student assistants to support module development in the digital learning environment. Regular newsletters and faculty stories increased visibility of good practices and recognised the work of dedicated colleagues.

Challenges

It is evident that the new programme also has some challenges. A first challenge we face is sustaining student engagement. This depends on how well the projects are organised and to what extent the professional competencies are truly integrated. Some competencies become less visible in later years. To address this, the e-portfolio was introduced to support continuity across years, complemented by short in-class reflection prompts that help educators reconnect to competencies addressed in earlier modules. Example 6 illustrates guiding questions to strengthen project management skills. Educators can use these to reinforce what was learned in earlier modules.

Example 6. Do students in your module work on a project?

To help students practise project management in a low-stakes manner, you can use short guiding questions during regular project meetings or reflection moments. These prompts make competencies visible and encourage students to articulate their planning and decision-making processes.

Guiding questions for students:

- Can each team member describe in their own words what needs to be produced? What conditions must this output meet? (acceptance criteria for output)*
- Has the team developed a milestone schedule for completing this project? Which tasks need to be completed first? Which are the dependencies between tasks?*

- *What risks do you foresee in the implementation of this project? How has the team planned to address or mitigate these risks?*

Educators can contact the project management expert on their campus for additional support, feedback or further examples.

A second challenge concerns the consistency of feedback and assessment quality. While students value feedback opportunities, they report variability in timing and usefulness. Educators, in turn, indicate a need for more support and tools to provide competency-based feedback. To address this, we have been working on feedback prompts and evaluation criteria in ready-made rubrics. However, while some competencies lend themselves to rubrics (e.g., writing skills), others (e.g., team dynamics) are harder to assess in a standardised way (if any assessment is desirable). Tools, such as FeedbackFruits, support structured (peer) feedback. This digital tool includes educator feedback (skills review and assignment review), student feedback (group member evaluation and peer assessment), and personal feedback (self-assessment of skills and self-assessment of work).

A third challenge relates to the complexity of large and open-ended projects. Engineering experiences integrate multiple learning goals and involve diverse stakeholders, which can lead to cognitive overload. Students may become overwhelmed, prioritise task completion over learning, or spend excessive time on projects. Variation in project design and coaching expertise can further affect whether intended learning outcomes are achieved consistently across teams.

A fourth challenge is sustaining faculty engagement within existing workload constraints. The success of the learning path depends on broad involvement and continuous professionalisation of teaching staff, which is not always self-evident. In addition, temporary contracts in academia require continuous investment in staff development and alignment.

Our experience shows that appointing teaching staff with an explicit focus on professional competencies — who coordinate across programmes, develop materials, and organise training — is crucial for successful implementation. However, these roles were not always formally recognised during the initial curriculum reform, which sometimes led to work overload and disengagement, in particular when some (technical) teaching staff were not yet convinced of the integrated approach, were reluctant to change, or were afraid to lose teaching hours. Although this is currently more widely acknowledged, in a context of budget constraints, this remains fragile: much of the workload associated with coordination, coaching, and iterative project design is less visible in formal teaching hours compared to other modules.

5.4 Lessons learned

The evaluation results show that integrating professional competencies into authentic engineering tasks enhances students' sense of relevance and supports the development of their emerging engineering identity. At the same time, variation in campus traditions, feedback practices, and project formats demonstrates that

implementing an integrated learning path requires continuous coordination, support, and reflection. Ensuring sustained visibility of competencies and maintaining a consistent coaching approach remain key points of attention as the programme evolves. In the next and final section, we translate these observations into concrete actions for you, educators and curriculum designers.

6 Recommendations and next steps

Based on the lessons learned, we offer seven recommendations that can support you in strengthening the development of professional competencies in engineering education. These recommendations are intentionally practical: they draw directly from approaches that proved valuable in our multicampus implementation and can be adapted to your specific setting.

6.1 Strengthen continuity and visibility across the curriculum

Professional competencies must remain visible beyond first-year projects. Extend opportunities for practice and reflection across modules throughout the programme. You can use clear signposting within modules — such as explicitly stating which competencies are addressed, using icons in weekly overviews, or making links in assignment briefs — to help students recognise that these competencies are integral to engineering practice, not just a module requirement. Advanced projects, electives, and internships offer opportunities for students to deepen and refine these competencies. Ensure that resources such as communication guidelines, presentation criteria, knowledge clips, or project management tools remain accessible throughout the entire bachelor programme, rather than being confined to individual modules.

6.2 Invest in professional development for teaching staff

Not all colleagues feel equally confident in coaching professional competencies. Targeted, low-threshold professional development initiatives — such as short workshops, lunch talks, or peer exchange sessions — can help educators become more comfortable with providing competency-based feedback and supporting students' development. In our faculty, the teaching team provide regular training sessions and talks, ranging from workshops at the faculty's educator day (e.g., 'Explore and experience: Toolbox Creativity and Innovation') to lunch talks (e.g., 'Peer feedback and writing skills: online and/or on campus?') to low-stakes guidelines for transfer of knowledge and skills to other modules. Making core materials easily accessible (e.g., templates, slides, feedback forms, examples of student work) helps educators integrate competencies without increasing workload.

6.3 Involve professional competency experts early in module design

Professional competency educators can make the greatest impact when they are involved from the start of module design or redesign. Early collaboration enables shared learning goals, coherent assessment expectations, and better alignment with the sub-learning paths. This prevents competencies from becoming late additions and fosters stronger integration with technical content. In practice, we observed that

modules redesigned in close collaboration with professional competency experts required fewer adjustments during implementation.

6.4 Enhance feedback culture with aligned tools and guidelines

High-quality feedback is essential for competency development yet challenging for educators and students alike. Faculty-wide rubrics, feedback prompts, and digital tools help create consistency. Tools such as FeedbackFruits have been particularly valuable for structuring educator, peer, and self-feedback. You can check with educators and students what works best in their context. For example, the educators preferred paper feedback forms for presentations (covering content, structure, storytelling, delivery, layout, and visuals). The forms are used across disciplines and academic years, improving clarity for both students and assessors. Encouraging students to provide peer feedback and to reflect on feedback received also strengthens their metacognitive skills and sense of ownership.

6.5 Support educators with concrete and transferable tools

Educators benefit from concrete instruments that help them integrate professional competencies into existing modules. Example 6 demonstrated how guiding questions about acceptance criteria, milestone planning, and risk identification can be used in any module involving project work. Similar checklists exist for teamwork, communication, or ethical reasoning. These small, practical instruments lower the threshold for integration and support colleagues who are less familiar with coaching in professional competencies.

6.6 Share success stories and strengthen peer learning

Colleagues are more likely to adopt new approaches when they see how others in their context have made them work. Sharing success stories — through newsletters, faculty events, or informal discussions — helps build a shared culture and encourages experimentation. Educators who personally experience the benefits of well-developed professional competencies in their modules become the best ambassadors. They can tell from experience that it is much more rewarding to evaluate a well-written lab report, observe a team that planned effectively, or see students adapt constructively to unforeseen challenges because they communicated well and organised their work thoughtfully. Also, stories from students describing how professional competencies supported their project work or internship experiences have shown to be highly motivating. These narratives highlight what works and what does not and help refine the learning path.

6.7 Monitor impact through a mixed methods approach

You can gain a more complete understanding of how students and staff experience competency development by combining quantitative and qualitative data. While longitudinal surveys track perceptions over time, interviews, focus groups, or informal reflection activities help uncover underlying reasons and nuanced experiences. Patience is important: implementing a coherent learning path is a long-term process and evaluating it requires time to allow practices to take shape and mature.

7 Conclusion

The iterative development and implementation of the learning path have shown that integrating professional competencies into engineering education is both feasible and impactful. At the same time, it requires ongoing collaboration, visibility, feedback, and evaluation. By strengthening continuity, supporting teaching staff, embedding consistent feedback practices, and monitoring outcomes, you can help students build a strong professional engineering identity and be better prepared for professional practice.

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AI statement

During the preparation of this work, the authors used Microsoft Copilot in order to improve the storyline and to check for grammar and spelling. After using this tool, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

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4.4

Developing Transferable Sustainability and Entrepreneurship Competencies through Vertically Integrated Projects at the University of Strathclyde

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This chapter examines the integration of Education for Sustainable Development (ESD) and entrepreneurship competencies within the Vertically Integrated Projects for Sustainable Development (VIP4SD) programme at the University of Strathclyde, in Glasgow, UK. Designed as a scalable model, VIP4SD embeds sustainability, interdisciplinary collaboration, and transferable competencies across undergraduate curricula by aligning research- (or inquiry)-based learning with Sustainable Development Goals (SDGs) challenge areas to effectively operationalise Research-Based Education for Sustainable Development (RBESD). The chapter traces the evolution of VIP4SD, its theoretical underpinnings, and its implementation across faculties. Recognising VIP4SD's alignment with institutional strategy and sector-wide momentum for ESD, the chapter offers practical guidance for its adaptation in different contexts. With a practitioner focus, it details mechanisms for competency development through scaffolded workshops and authentic assessment, enabling students to recognise, reflect on, and articulate their growth throughout their project journeys. This approach enhances students' self-awareness, reflective capacity, and employability. VIP4SD is presented not only as a curricular innovation, but as a strategic vehicle for embedding competency-based, sustainability-driven education across higher education.

1 What is VIP4SD and how did it evolve?

1.1 *The Strathclyde context*

With around 30,000 students and 3,500 staff, the University of Strathclyde is a leading technological university in Glasgow, the UK's sixth most populated city. It comprises four faculties: Engineering, Science, Humanities and Social Sciences (HaSS), and the Strathclyde Business School.

The Vertically Integrated Projects for Sustainable Development (VIP4SD) programme began in Engineering and has since expanded across all faculties, though unevenly due to curriculum and resource constraints. Engagement is strongest in Engineering (involving around 45% of students, mainly in two departments) and in HaSS (ca. 55%, largely through the School of Education), with limited participation in Science and the Business School (ca. 10% combined). The university is encouraging of wider VIP4SD participation where possible to enable more interdisciplinary undergraduate research collaboration of the type outlined in section 1.5.

1.2 *Origins and emergence of VIP*

Vertically Integrated Projects (VIP) is a model invented by Professor Ed Coyle at Georgia Institute of Technology (GTech) to integrate research-based education (RBE) into undergraduate curricula. It was introduced at the University of Strathclyde in 2012.

The VIP model evolved from his previous work on Purdue University's Engineering Projects in Community Service (EPICS) programme (Allebach, 2006; Jamieson et al., 1996), which began in 1995 with the aim of engaging engineering students in long-term, community-focused projects. A vertically integrated dimension to the project structure was developed to enhance project sustainability and continuity. This was achieved by enabling students across different year groups to stay involved with the same project for multiple years (i.e., vertical integration), which had the consequence of creating project teams filled with students from different years of study. To encourage greater staff participation, the project pivoted towards the inclusion of a research dimension alongside community engagement, where staff could align their team's objectives with their research interests while retaining the strong civic ethos of EPICS. This approach fostered the development of research competencies and skills in undergraduate students as well as sustained staff involvement.

This VIP model has since been honed and mainstreamed at GTech, where one in every three of their graduates have benefited from participation in the VIP programme. 50+ universities across the world now operate VIP programmes as part of an international consortium (VIP Consortium, n.d.), including the University of Strathclyde, where around 250-300 students per year participate. Strathclyde has expanded VIP across faculties and sustained a stable, institution-wide programme since its introduction in 2012. It was also the first institution within the consortium to intentionally align its VIP programme with the UN Sustainable Development Goals (SDGs) (United Nations, 2015) and to position the model as a vehicle for explicitly embedding Education for Sustainable Development (ESD), entrepreneurship, and competency development

within the curriculum. This led to its rebranding of the programme in 2017 to Vertically Integrated Projects for Sustainable Development (VIP4SD). This chapter explains how that evolution took place and how the model now operates.

1.3 Theoretical foundations of VIP

From a theoretical standpoint, the VIP model is an active and experiential form of research-based education (Christie & De Graaff, 2016; Jamison et al., 2022), where students have the potential to become co-producers of knowledge through authentic, inquiry-driven research collaboration with staff and peers across different levels (vertical integration) and disciplines (horizontal integration). This aligns with (Griffiths, 2004; Healey & Jenkins, 2009) frameworks by moving beyond research-led or research-oriented teaching to fully immerse students in collaborative, interdisciplinary research projects, where they have the opportunity to develop the types of transferable competencies and skills that are rarely cultivated through traditional, subject-based teaching, where students act as passive recipients of knowledge. Furthermore, by providing staff and students with this vertical project pathway they gain the opportunity to build momentum and working relationships that are conducive to their ongoing competency development and the strengthening of their domain knowledge.

1.4 VIP4SD – embedding research-based ESD

Aligning our VIP programme with the SDGs had the planned effect of not only highlighting to academic and research staff the alignment of their research with the SDGs, but also appealing to the sensibilities of our students, who are keen to apply their disciplinary knowledge and develop research skills and other competencies in projects aimed at delivering genuine societal and/or environmental impact (University of Strathclyde, 2025b).

The UNESCO definition of ESD highlights how the SDGs act as contextual drivers for the development of key competencies through the application of transformative pedagogies (UNESCO, 2017, 2020). It underscores the critical importance of applying and cultivating these competencies and skills to *"equip people with the knowledge, skills, values, and attitudes to create positive and sustainable futures for both current and future generations"*.

The three pillars of ESD (SDGs, competencies, and transformative pedagogies) are also integral to the CoDesignS ESD Framework (Toro-Troconis et al., 2024), which is designed to support the integration of ESD in the curriculum (ALDESD, n.d.). When research-based education is used as a pedagogical approach to embed ESD within the curriculum, the SDGs can serve as context or a thematic lens through which students can actively engage with authentic, real-world discipline-specific and interdisciplinary research challenges. This requires students to actively apply and cultivate a range of transferable competencies and skills aligned with those defined by UNICEF (2019), but also sustainability competencies, such as systems thinking, anticipatory reasoning, normative competency, and strategic thinking as defined by UNESCO (2017). These competencies are integral to both future professional and personal development. The

nature of these global challenges also presents fertile ground for interdisciplinary student and staff engagement within our VIP4SD programme through *horizontal integration* across departments and faculties.

1.5 VIP4SD – horizontal (interdisciplinary) integration

While the SDG anchor may not be as central in other institutions across the 50+ member consortium as it is at Strathclyde, our leadership in this area has influenced many partners to map their projects to relevant SDGs. This also led to the promotion of interdisciplinary RBESD, that is, horizontally integrated projects, enabling students from different disciplines to work collaboratively towards a common project objective, led by academic staff. Not all projects at Strathclyde are interdisciplinary, often due to curricula constraints, discussed in Section 3 and 7, but almost all have an engineering focus. Where interdisciplinarity can be justified and supported, the projects and the students have the opportunity to benefit greatly as the open-ended and ill-structured (so-called 'wicked') problems that they focus on. These often require multiple disciplinary perspectives, unlike project-based learning, where the focus is often on the delivery of a well-specified product by a cohort from a shared discipline (Brassler & Dettmers, 2017). Therefore, where an interdisciplinary dimension exists, this enables students to develop specific communication skills that involve articulating and exchanging disciplinary knowledge across disciplinary boundaries, involving communication using shared vocabularies, and recognising and respecting the complementary contributions other disciplines can make toward achieving a unified, successful project outcome.

Example 1. The GridMaster

The GridMaster VIP4SD project consists of a combination of Electrical and Electronic Engineering students and Computer Science students, focusing on the development of a software tool that supports the design and cost estimation of minigrids for deployment in Sub-Saharan Africa. It is supported by a social enterprise and university research group with specific interests in Malawi.

Example 2. Apps4Good

Apps4Good is a VIP4SD project where Electrical and Electronic Engineering, Computer Science, and Business students work together to develop an app that supports a homelessness charity's street-outreach work. The app lets members of the public pin the location of people who appear to be sleeping rough, triggering notifications to volunteers, who then self-select attendance based on proximity and other priorities. Engineering and computing students lead the technical development, while business students design marketing strategies to raise awareness and encourage public engagement with the app.

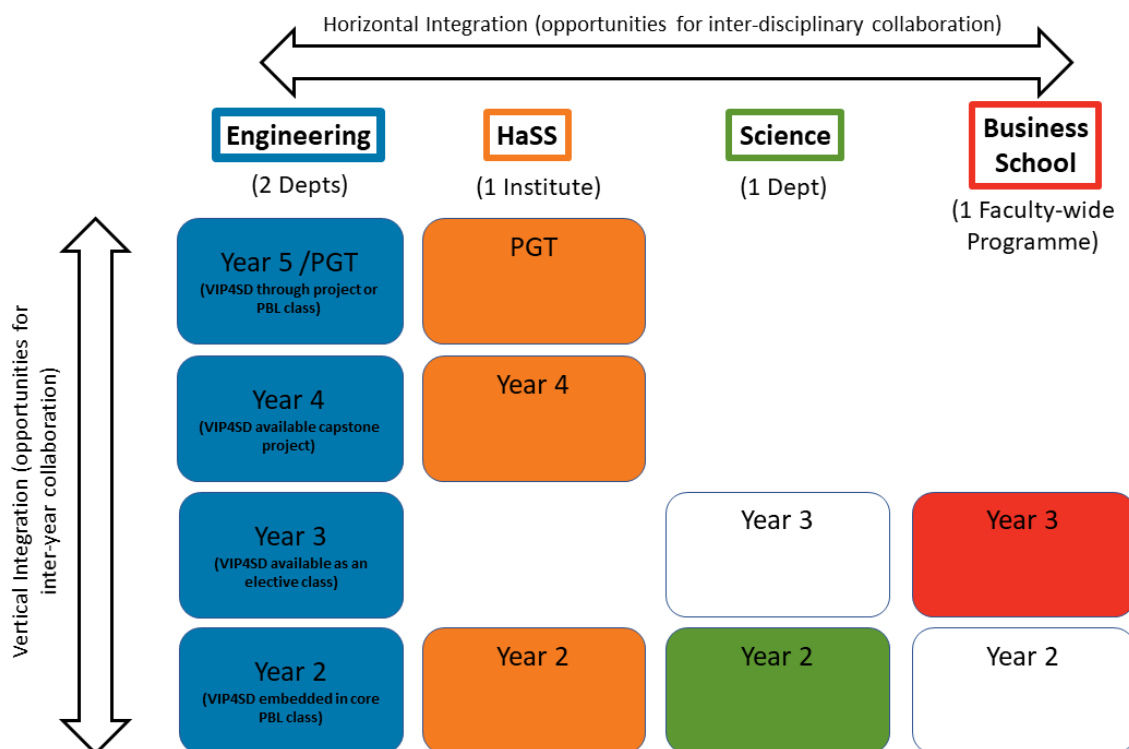


Figure 4.4.1: VIP4SD structure (Own Work by authors)

Fig. 4.4.1 illustrates the current VIP4SD structure across all four faculties. One Engineering department has a fully developed vertically integrated pathway, with the highest retention in Year 3 and options for students to continue through existing capstone and group projects. Other faculties are still developing their pathways. Empty boxes indicate potential curricular space for embedding VIP4SD, while blank areas show years where space is currently limited or absent, though these could be reconsidered in future curriculum reviews.

1.6 VIP4SD – Entrepreneurial mindset development

In addition to transferable, sustainability, and interdisciplinary competencies, the VIP4SD model at Strathclyde also focuses on the development of entrepreneurial mindset competencies: collaboration, communication, resilience, forward thinking, and value creation, following the framing and definitions offered by Mawson and Casulli (2024). They define the entrepreneurial mindset as “*a set of learnable cognitive and emotional competences conducive to developing and enacting behaviours to support value creation activity*”, emphasising that these mindsets are not innate but can be developed and directly linked to creating value.

The vertically integrated of VIP4SD and the close, ongoing partnership it fosters between students and research staff provides the conditions in which these competencies are developed effectively. It offers students sufficient time, space, and collaborative environment, often absent from more conventional approaches to

student project work and supervision, because they only typically span a single academic year. This allows students to build momentum and develop genuine levels of domain expertise, become knowledge producers, and develop key competencies and skills that are substantive, including leadership, mentorship, and interdisciplinary working. In practice, collaboration and communication are embedded in daily activity; resilience and forward thinking are exercised in the face of uncertainty; and value creation is central, as success is measured through collective outcomes and impact rather than examinations. In early 2024, new project-led guidance and targeted workshops were introduced to help students recognise and articulate these competencies. VIP4SD now continues as a research-based approach to embedding ESD, while more intentionally and explicitly embedding competency-based education which also encompasses the entrepreneurial mindset.

2 Getting institutional buy-in for VIP4SD

2.1 Alignment with Strathclyde ethos

When VIP was first introduced to Strathclyde, its alignment with the University's ethos as "*the place of useful learning*" was immediately evident. The prospect of creating a programme that enabled students to apply their disciplinary knowledge in a meaningfully impactful, and therefore genuinely *useful* way, provided a compelling rationale for launching a pilot initiative, initially housed within the Faculty of Engineering.

The programme's subsequent alignment with the SDGs and entrepreneurial mindset further reflected Strathclyde's identity as a socially progressive, globally engaged institution, and so embedding these values into our teaching and learning was a logical extension that gained high-level buy-in early on.

2.2 Global advocacy and sector-wide demand and momentum for ESD

Advocacy for ESD across all levels of education had already gained significant momentum through global initiatives such as the UN's Decade of Education for Sustainable Development from 2005 to 2014 and the ESD for 2030 framework introduced in 2021 (UNESCO, 2020). These efforts, coupled with rising demand from students and employers (Dryson, 2015; SOS UK, 2025) have catalysed wider change across the higher education sector, prompting professional engineering institutions (Royal Academy of Engineering, 2024), professional practice bodies (ADVANCE HE et al., 2021), quality assurance agencies (QAA, 2023), and UK-based education-focused charities, such as AdvanceHE, to take more active roles in driving and supporting tangible systemic change to embed ESD in the higher education curriculum. Furthermore, a green competencies and skills gap was highlighted in the National Grid's report *Building the net zero energy workforce* (Dahl et al., 2022); similar challenges exist across Europe as a whole.

2.3 Shifting perceptions and a strategic opportunity for the expansion of ESD and competency-based education

Building momentum and demand has led higher education institutions to move from viewing ESD and entrepreneurship as adjunct, add-on, co-curricular, or optional offerings to something that should be fully integrated, mainstreamed within curricula, and made consistently available to all students through the core curriculum.

This evolution has transformed the dynamics of curriculum change around ESD and entrepreneurship integration, where an internal demand and strategic pull now exist due to the external levers in place. Consequently, faculties at Strathclyde must now actively seek proven, scalable approaches to integrate ESD and entrepreneurship into their programmes, which opens doors for initiatives like VIP4SD to expand.

Many institutions have gone further and enshrined their commitment to embedding ESD and entrepreneurship education within strategic objectives and/or KPIs. At Strathclyde, a KPI was introduced that commits to ensuring *"all education programmes have programme-level learning outcomes related to ESD by 2027, which encompass the integration of the UNESCO Education for Sustainable Development skills and competencies"*. A strategic objective was established to embed entrepreneurial mindset education into the Strathclyde student experience by *"building a range of experiential learning opportunities which equip students with entrepreneurial competencies"* (University of Strathclyde, 2025a).

Despite VIP4SD offering a proven approach to embedding ESD and entrepreneurship in the curriculum, barriers to operationalising and scalability persist, particularly related to siloed curriculum structures and resource allocation. The next section addresses these challenges.

3 Operationalising VIP4SD at Strathclyde

3.1 From pilot to scale-up

VIP4SD was initially developed as a pilot programme, attracting approximately twenty students, all coming from one Engineering department at Strathclyde. Even at such a small scale, the pilot programme offered a useful means of gaining insights into the resource requirements and the curriculum constraints associated with the programme implementation, highlighting the challenges that might be expected when opening and scaling the programme up across other departments and faculties.

The VIP4SD programme now regularly attracts approximately 250+ undergraduate students every year, with most coming from Years 2 and 3 of their degree. Some students will continue to engage with VIP4SD into Year 4 through their capstone project. While this is not groupwork, if students continue their VIP4SD research interests into this project, they can remain an integral part of the VIP4SD team, often assuming a leadership role. While their project may be complementary to the VIP4SD team's objectives, care must be taken by supervisors to ensure the individual student project is not dependent on VIP4SD group project output, to avoid any risk of compromising the student's output and final grade.

3.2 Curriculum integration challenge of finding vertical pathways

The main challenges for VIP4SD are finding space in the curriculum and identifying vertically integrated pathways through each year of the curriculum that allow students to engage with the same project for multiple years. While common challenges to the implementation of VIP4SD exist across institutions, faculties, departments, and degree programmes, a tailored approach to its implementation within any given context is often required. Fundamentally, at Strathclyde, this has involved identifying existing modules with learning outcomes centred on professional skills development, often found in established project-based modules. These modules typically enable students to engage with pre-defined project topics that support the application of disciplinary knowledge, while cultivating key competencies such as collaboration, project management, problem solving, and reflective practice.

Such modules can serve as effective container classes or surrogates for VIP4SD projects; where they span successive years of study, they offer the potential to establish vertically integrated pathways, allowing students to return to the same project across multiple years. In cases where pre-existing container modules do not exist in a study year, where possible, new elective or optional modules can be developed to accommodate VIP4SD.

3.3 Supervision and peer-led mentorship structures

Resourcing is a critical consideration in curriculum development, especially where project-based learning requires sustained supervisory input, which results in higher staff/student ratios than more efficient (though less active) teaching modes. The VIP4SD model helps offset this perceived supervision burden by embedding peer-to-peer mentorship as a core feature of its team-based structure: students with more VIP4SD experience organically assume leadership roles, onboarding and mentoring incoming members.

This onboarding process enables senior students to develop leadership and facilitation skills (Lu et al., 2016), while junior members benefit from scaffolded support from their peers. This rapidly brings them up the learning curve to become productive knowledge and project contributors earlier on in their VIP4SD journey than would otherwise be the case.

VIP4SD supervisors act as research directors, meeting with their teams every couple of weeks, while teams are expected to meet regularly in sub-groups and/or outside supervision meetings. Groups ensure accountability through taking of formal meeting minutes, and prepare agendas for supervision meetings, ensuring students take responsibility for driving these meetings, fostering professional practice. Additional supervisory support may come from PhD students, particularly when the project aligns with their research interests.

4 Translating the VIP4SD experience into recognised competencies and skills

4.1 *From implicit to explicit: recognising competency development*

The VIP4SD programme has been successfully implemented across multiple departments, despite the challenges highlighted around curriculum space in Section 3. The cumulative effect has been that VIP4SD at Strathclyde has operated at a scale comparable to that of a standard cohort, demonstrating its viability as a mainstream curricular offering.

During this time, students engaged constructively with diverse areas of research and development topics, underpinned by a wide range of SDG challenges, from improving energy access in developing countries to creating STEM resources for primary schools and developing healthcare solutions. However, students' skills and competency development were generally regarded as implicit until recently (circa 2022). The intuitive assumption was that if students could demonstrate a tangible and constructive contribution to project objectives, both individually and as part of a well-functioning team, then this provided sufficient evidence of their ability to apply transferable competencies such as problem solving, collaboration, communication, and resilience. However, the same assumption was not necessarily made for less successful projects, where success was measured in terms of the group's meeting project objectives. This neglected the fact that competency development can often become stronger with increasing project adversity, and so project success may not necessarily be a proxy measurement for competency development. Also, these more familiar competencies are often easier for students and staff to recognise and connect with, as they sit within cognitive and psychological domains rather than more intangible competencies associated with the affective domain.

It was therefore acknowledged that a gap existed between project output, competency development, and competency articulation. While students were developing and applying relevant competencies through authentic project work, there was limited structured support to help them recognise, evidence, and transfer this learning (including from failure) into employability contexts. This challenge mirrors a broader issue in engineering and higher education. Research-based and project-based pedagogies often assume that authentic practice is sufficient for skills development (Kirschner et al., 2006). As Brown et al. (1989) argue: unless students are scaffolded to reflect on, evidence, and communicate their growth, much of this learning remains tacit.

4.2 *Scaffolding competency articulation: Enhancing employability and self-awareness*

VIP4SD coordinators and supervisors increasingly recognised that students needed more targeted, practical support to fully benefit from the experience, by making competency development more explicit and communicable, without encroaching on the capacity of teams to focus on their research and delivering impact in their particular SDG challenge area. It was established that students required clearer

scaffolding to help them identify and articulate their competency development throughout their VIP4SD project journey. This would strengthen their employability credentials by enabling them to clearly articulate and evidence to prospective employers their project contributions, framed in terms of the competencies they applied and developed throughout, and how these translated to outputs. At a meta-level, enhancing the students' abilities to recognise and articulate these competencies also serves to strengthen their self-awareness competency as well as their communication skills.

The approach taken to the scaffolding of students' competency articulation was to engage students in a series of workshops delivered by the Careers Service and Strathclyde Inspire, the University's dedicated 'Entrepreneurship for All' support unit, that was created to support its 2030 strategic commitment to mainstream entrepreneurship education.

5 Supporting VIP4SD students to recognise and articulate their competency development

5.1 *Student journey overview*

The competency workshops run across the academic year, with two delivered in semester 1 and two in semester 2. They are strongly encouraged for students enrolled in VIP4SD, though not mandatory. VIP4SD's vertically integrated structure means students participate across different years and programmes, making universal scheduling impractical. Workshops therefore run on Wednesday afternoons, an institutionally protected co-curricular period. Attendees are primarily from Engineering and Science disciplines, though representation varies by project.

The workshops complement project activity by providing structured opportunities for students to reflect on VIP4SD experiences and articulate competency development. Across the four sessions, a Modelled-Scaffolded-Independent approach (Beed et al., 1991) supports the development of STAR (Situation, Task, Action, Result) reflection capability (National Careers Service, 2024). The first workshop models examples; later sessions progressively reduce facilitator support, and the final workshop requires students to articulate competencies independently with peer interaction and optional facilitator feedback.

5.2 *Workshop design*

Each session follows a consistent format of reflection, group activity, articulation practice, and signposting to optional development opportunities. Students first engage with their own experiences, then identify their competencies through collaborative tasks, and finally practise communicating their learning using the STAR framework.

Each workshop covers one Strathclyde entrepreneurial mindset competency as the main focus; however, UNESCO sustainability competencies were also referenced and signposted to encourage further reflection with respect to these competencies.

Collaboration workshop

Students complete a constrained group task titled 'Collaborate in Confines'. Each group designs a mascot representing Strathclyde's 2030 strategy, under communication restrictions: one student asks questions only, another draws only, and the third answers, using only 'yes', 'no', or 'more'. The activity draws on desirable difficulties (Bjork & Bjork, 2011), where learning is strengthened through manageable obstacles. Collaboration becomes necessary rather than optional, requiring groups to negotiate roles and adapt communication strategies.

During reflection, students connect the activity to project tensions. Interdisciplinary teams describe challenges aligning technical feasibility with partner, user, and collaborator expectations, particularly when disciplines approach problems differently. STAR reflections often reference miscommunication delaying progress and requiring clearer roles and shared decision making. The workshop mirrors these dynamics, allowing students to rehearse collaborative adjustment before returning to their projects.

Value creator and anticipatory thinker workshop

This workshop explores how students define and pursue value. Students begin by mapping value across personal, academic, professional, and competitive contexts. This encourages recognition that value creation extends beyond financial outcomes to include social and personal impact. Students then produce a value creation statement in the format: 'In [situation], I want to create [value] because [reason].' This structure requires them to define context, type of value, and motivating purpose, moving abstract ideas of value into concrete intentions.

Example 3. GridMaster VIP4SD value creation statement

In developing a minigrid design tool in the GridMaster VIP4SD project, I want to create technical, social, and environmental value by enabling minigrid developers to quickly and accurately design and estimate the cost of minigrids, because this will help them design minigrids that are suitably sized and costed, ultimately ensuring their investments are sound — meaning communities benefit from affordable and reliable, clean sustainable energy systems.

Example 4. Apps4Good VIP4SD value creation statement

In developing an app within the Apps4Good VIP4SD project, I want to create social and operational value by designing an app that enables members of the public to pin the location of rough sleepers, so that volunteers in the charity's street team can respond more efficiently and effectively, because this will improve the timeliness and quality of support and care provided to people experiencing rough sleeping.

Forward thinking is introduced as the mechanism for achieving these aspirations. Students complete a reverse-engineering exercise identifying routines, mindsets, and

commitments supporting success. The activity emphasises transferable practices that support long-term progress and aligns with backcasting (Dreborg, 1996), where a desired outcome is identified and the steps required to reach it are mapped backwards.

During shared STAR reflections, students often ground value creation in ongoing project goals. Teams working on sustainability challenges articulate value beyond technical outputs, including community engagement, behaviour change, or environmental impact. When applying forward thinking, students reference planning cycles, prototype iterations, and deadlines. The reverse-engineering activity prompts reflection on how practices, documentation, and accountability influence long-term project outcomes.

Resilience workshop

The resilience workshop asks students to consider how they respond when things do not go to plan. The session distinguishes persistence from resilience: persistence involves repeating the same action, whereas resilience involves adaptation, learning, and progress. This reframes resilience as an evolving capability rather than simple endurance.

Students reflect on experiences of failure and discuss what they learned from them. Drawing on growth mindset theory (Dweck, 2016), setbacks are reframed as feedback that supports development. Rather than signalling inability, challenges become opportunities to refine strategies and improve understanding.

During STAR reflections, students frequently cite technical setbacks or miscommunication as moments requiring resilience. Discussions often shift from frustration to learning when these experiences are reframed through growth mindset principles. Reflections move from describing a failed attempt to articulating how consultation, redesign, or revised testing improved understanding of the project process.

Effective communication workshop

The final workshop supports students in communicating competency development achieved through VIP4SD. Drawing on Mawson and Casulli (2024), students practise articulating experiences using the STAR framework in interview-style scenarios. Positioned at the end of the workshop series, the session builds on experiences gained through both project work and earlier workshops.

Students initially describe achievements in broad, collective terms. Through iterative rehearsal and peer feedback, explanations become more precise. Students refine their articulation to clarify individual responsibility, decision making and impact within the team.

Effective communication functions as the capstone competency. Competency development carries limited professional value if it cannot be clearly evidenced. This workshop ensures students leave with both substantive experiences and the ability to articulate them confidently in professional contexts and settings.

6 Authentic assessment in VIP4SD programme

Authentic assessment focuses on students' ability to undertake tasks and deal with situations they might experience in their personal or professional life. This section presents forms of authentic assessment that have been incorporated into the VIP4SD programme at Strathclyde to support students in the articulation and development of key competencies.

Assessment includes a group poster presentation at the Strathclyde Sustainability Festival, a short group executive summary, and an individual competency-based interview, in addition to one formative competency reflection in each semester.

6.1 Competency-based interviews

Mock competency-based interviews were introduced as an assessment piece to offer students an active and authentic form of assessment designed not only to evaluate students' ability to evidence and articulate their development (i.e., assessment of learning), but also to act as a learning experience encouraging reflection and growth (assessment as learning), and ongoing competency development (assessment for learning).

Here, assessors and students role-play interviewer and interviewee respectively, providing an opportunity for assessment, but more importantly a practical and developmental benefit that readies students for the real-world demands of presenting themselves and articulating their attributes in job interviews and assessment centres.

The theoretical framing for this approach drew on theories regarding assessment for learning, emphasising that assessment should function as part of the learning process rather than as a detached measurement exercise (William, 2011). By deliberately designing the assessment to be both summative and evaluative, and educational and formative, this method sits at the nexus of assessment of, for, and as learning (Earl & Katz, 2006). It thus addresses the so-called 'competency articulation gap' (Kovalcik, 2019), by supporting students in the effective communication of their competencies for employability.

6.2 Poster presentation and VIPer pitch symposium

Embedding a poster assessment within an event such as the Strathclyde Sustainability Symposium elevates it beyond routine assessment, by providing students with an authentic, real-world environment to showcase their work to a diverse audience. Many programmes use similar approaches through simulated tradeshow or showcase events that blend assessment with public engagement.

This format develops key competencies such as communication, problem framing, and critical thinking, as students must tailor explanations to audiences with different levels of expertise and knowledge. The poster presentation format introduces a constructive pressurised environment where students are required to be more agile in their interactions, which builds confidence, resilience, and professional composure. This also builds networking skills in both academic and industry contexts, and encourages peer engagement, with students acting as critical audiences for one another.

The VIP4SD programme includes an informal assessment called the VIPer Pit, an investor-style pitch competition held during the Sustainability Symposium. While it carries no academic credit, teams are incentivised by the opportunity to voluntarily pitch for project funding provided by the Lady Curran Fund through the University's Alumni and Development Department.

Students gain valuable experiential learning by submitting a short, pre-recorded pitch video and then taking part in a live Q&A with a panel of senior professionals before the symposium audience. This encourages students to engage professionally, developing competencies such as communication, critical thinking, resilience, and strategic thinking, which judges probe during Q&A. The VIPer Pit offers an authentic platform for students to engage in authentic professional practice, develop confidence, and invest further (personally and financially) in their VIP4SD projects.

7 Recommendations for implementation

This section outlines recommendations, drawn from the programme team's experience in developing and running VIP4SD, to support practitioners seeking to establish similar programmes.

Embed research-based education for sustainable development (RBESD). This means integrating RBESD into the core curriculum rather than limiting it to optional or peripheral modules to offer students sustained opportunities to engage with RBESD throughout their degree.

Connect RBE with ESD (RBESD). Frame RBE projects around the SDGs to demonstrate the role of students' disciplines and the importance of interdisciplinary engagement in addressing these sustainability challenges and delivering positive societal and environmental impact.

Use the VIP model to embed RBESD. This offers a vehicle for the delivery of RBESD, where vertical integration provides the space and time for students' competency development normally associated with intensive placement and internship experiences.

Legitimise ESD and competency development through quality assurance. Embed ESD and competencies in QA processes and mechanisms, making this structurally unavoidable (e.g., through dedicated sections in module descriptor forms requiring faculty approval and by encouraging sustainability challenge and competencies in module and programme learning outcomes). This will also support accreditation.

Engage staff and early career researchers. Aligning projects with staff research interests sustains engagement, while early career researchers build research management competencies and skills by leading VIP4SD undergraduate teams, offering opportunities for their own development and access to an untapped research resource.

Engage external partners. Stakeholder engagement raises the stakes for the students and engages them in a deeper level of learning and competency development. This

also strengthens links with industry for co-supervision and opportunities for real-world validation of project outcomes.

Integrate interdisciplinary within the programme (i.e., horizontal integration). Although often constrained by siloed curricula, creating cross-faculty and interdisciplinary collaborations can substantially enhance students' competency development, but requires careful curriculum planning. Partnering with like-minded colleagues in other faculties helps establish effective mechanisms for inter-curricular engagement.

Map vertical pathways. It can be difficult to find a vertically integrated curriculum pathway across different years of the programme. Therefore, collaborating with programme directors and module leaders is key to identifying existing project-based classes across years to carve out vertical pathways. Avoid wasting energy in departments where it may be clear the programme or VIP model is not going to fit.

Provide scaffolded support through structured workshop. Work with Careers and Entrepreneurship teams to help students articulate their competencies without disrupting project work. This support can be reduced as their confidence grows. Because reflective articulation is unfamiliar, some students will need time to recognise its value and may initially resist if the relevance to their VIP4SD project is not immediately clear or linked to employability.

Include the affective domain — resilience, self-awareness, and normative competencies are critical. While professional and transferable skills often emphasize cognitive and practical domains, the affective domain fosters emotional intelligence, ethical reasoning, and personal growth, which are vital to prepare students to navigate complex, real-world challenges with empathy and integrity.

Use authentic assessment to enhance learning and employability. Employing assessment formats such as mock interviews, poster presentations, and investor pitch competitions can provide authentic opportunities for students to both develop and showcase their competencies.

Align with institutional ethos and strategic aims and sectoral transformations. To gain buy-in at all levels, position VIP4SD within the university's strategic identity and ethos. Align it with KPIs and strategic institutional priorities (e.g., employability, sustainability, internationalisation, etc.), and sector-wide levers for change (e.g., accreditation, quality assurance requirements, etc.).

Use peer mentorship to accelerate onboarding and foster leadership. Embed peer mentorship structures to reduce supervisory burden, enhance team cohesion, and provide opportunities for students to demonstrate leadership and mentorship capabilities.

Keep workshop sessions short and engaging. The workshop activities do not need to mirror the projects themselves. The value of the workshop activity lies in identifying competencies, not in producing outputs for assessment. A safe, engaging, low-stakes

environment allows students to be honest and properly reflect on their assumptions and understandings.

Equip project leads. Project leads must be confident in the competency framework to sustain dialogue and build effective questioning in assessment settings. Academic leads should be supported through pre-assessment sessions, strengthening their ability to challenge students' reflections and mirror professional interview contexts.

8 Conclusion

The introduction of competency workshops within VIP4SD represents a transition from implicit to explicit competency development. By retaining the authenticity of research-based, interdisciplinary projects, while providing structured opportunities for reflection and articulation, the programme has enhanced both educational and employability outcomes. Students not only develop collaboration, communication, forward thinking, resilience, and value creation skills — which they would also have developed through participating in the innovative research approach — but they also learn how to evidence these competencies in ways that improve their employability outcomes. The Strathclyde approach demonstrates a transferable model for making competency development tangible and impactful and offers a pathway for institutions seeking to embed competencies associated with education for sustainable development and the entrepreneurial mindset across their curriculum.

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Integrating Self-Directed Learning: Professional and Personal Development in the Industrial Design Bachelor Programme at Eindhoven University of Technology

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This chapter presents the curriculum redesign of the bachelor programme in Industrial Design at Eindhoven University of Technology (TU/e), with a focus on designing a Professional and Personal Development (P&PD) learning trajectory within a competence-centred learning framework. Aligned with the TU/e Bachelor College redesign, the initiative aims to enhance employability by strengthening competencies acquired both inside and outside formal coursework. Central to this approach is self-directed learning (SDL), which fosters autonomy, adaptability, goal setting, and lifelong learning, skills vital for addressing complex design challenges in rapidly evolving technological contexts. The P&PD learning trajectory, integrated throughout the programme, guides students in shaping a professional identity while applying competencies in authentic contexts through a complementary challenge-based learning (CBL) programme. Supported by coaches on project contents and professional development, students connect personal growth with professional practice in a collaborative and student-centred environment. The redesign process drew on van den Akker's curriculum principles systems and design thinking, and on Biggs' constructive alignment to ensure coherence among outcomes, activities, and assessment. Bloom's taxonomy was used to align learning outcomes across academic years. A participatory approach involving faculty, staff, and stakeholders helped foster a sustainable culture of educational innovation. Insights from students, coaches, and programme management indicate that the renewed SDL framework effectively supports the development of five interconnected competencies and skills essential for industry-ready designers. The P&PD learning trajectory, and particularly its SDL component, demonstrates positive effects on student learning and offers transferable lessons for institutions seeking to embed SDL and CBL into their curricula.

1 Introduction

The Department of Industrial Design (ID) at Eindhoven University of Technology (TU/e) has developed an educational model that is both innovative and responsive to the rapidly changing demands of society, industry, and technology. Grounded in a competency-based educational philosophy, the curriculum emphasises not only the acquisition of knowledge, competencies, and skills, but also the development of professional attitudes and behaviours that enable students to act as reflective, responsible, and adaptive design professionals. Central to this model is student-driven learning, in which learners actively shape their development pathways through authentic design projects, interdisciplinary collaboration, and engagement with real world challenges. To further support this, a Professional and Personal Development (P&PD) learning trajectory, evolving from the earlier Professional Vision and Identity (PV&I), was integrated to strengthen competence development and professional growth.

Established in 2001, the ID department was founded to educate a new generation of design engineers capable of bridging technology, human needs, and societal challenges. From its inception, the programme aimed to prepare graduates to conceive and develop intelligent systems, products, and services within complex societal contexts. This vision is reflected in the integration of design practice, scientific inquiry, theory, and reflection, fostering a continuous interplay between doing, thinking, and learning. Students work on real world challenges through challenge-based learning (CBL) projects, often in collaboration with research staff and a broad ecosystem of external societal and industrial partners (Doulougeri et al., 2024).

Within this flexible curriculum, self-directed learning (SDL) enables students to make informed choices regarding projects and modules, effectively designing their own learning paths. Students are supported in this process through mechanisms such as project markets, where they explore content and learning requirements of available projects before making deliberate selections. This approach empowers students to take ownership of their learning, to experiment and iterate, and to construct a professional identity aligned with both personal aspirations and societal needs. As a result, the ID educational model has gained recognition as a distinctive and influential example within Dutch higher education (Gómez Puente & Doulougeri, 2022; Hummels et al., 2011; Van Diggelen, 2020).

In the context of rapid technological advancement, global challenges, and evolving labour markets, SDL has emerged as a vital competence for 21st century professionals. Within engineering education, SDL supports learners in developing the cognitive, emotional, and metacognitive capacities necessary to navigate uncertainty and interdisciplinary innovation (Candy, 2004). The emphasis on ownership, reflection, collaboration, and community learning within the TU/e ID curriculum therefore aligns strongly with contemporary understandings of SDL as an essential competency in higher education.

This chapter presents an empirically grounded case study on how self-directed learning can be embedded at curriculum level within engineering and design education. By linking educational theory to concrete practices in the TU/e ID programme, the chapter supports the handbook's aim of connecting conceptual frameworks with practical examples that inform educational innovation across contexts.

1.1 Theoretical framework: exploring the concept of self-directed learning empirically

Self-directed learning is commonly understood as the ability to intentionally plan, monitor, and reflect on one's learning journey in pursuit of personal, academic, or professional goals (Ahiskali, 2024; Beagon et al., 2025). It encompasses identifying learning needs, setting goals, selecting and applying strategies, and evaluating outcomes (Beagon et al., 2025). Rather than a natural ability, SDL is a learnable and teachable set of skills that underpin lifelong learning, and is an essential attribute for engineers, whose professional growth extends beyond formal education (English & Kitsantas, 2013).

Contemporary perspectives on SDL provide a lens for understanding the curriculum of the ID department at TU/e. In this context, student autonomy is framed as integrated competencies, such as metacognition, motivation, and professional identity development, underpinning the department's student-driven, project-based approach (Kanar & Bouckennooghe, 2021). Within the TU/e ID curriculum, students take ownership of their learning by engaging in authentic design challenges, iterating on solutions, and reflecting critically on process and outcomes. This aligns with the 21st-century skills framework (Binkley et al., 2011), where SDL intersects with critical thinking, creativity, and initiative, explicitly nurtured in design projects and collaborative learning communities.

Zimmerman's (2002) cyclical model of self-regulated learning — forethought, performance, and self-reflection — provides a theoretical underpinning for the TU/e ID approach, highlighting how students plan, execute, and evaluate design activities in iterative cycles. Garrison's (1997) conceptualisation of SDL as the interplay of self-management, self-monitoring, and motivation aligns with the curriculum's emphasis on autonomy, collaborative responsibility, and goal-directed learning. Knowles' (1975) work on adult learning reinforces intrinsic motivation and learner autonomy, embedded in the curriculum through self-directed projects, cross-disciplinary collaboration, and reflective practices. Together, these perspectives illustrate how the TU/e ID model operationalises autonomy, translating principles into learning experiences that prepare students for complex, real-world design challenges.

Building on these perspectives, the following section (1.2) explains how SDL constructs are implemented in the TU/e ID curriculum. This shift from theory to practice shows how these frameworks inform design decisions, scaffolding strategies, and educational interventions. Sections 2 and 3 therefore illustrate how SDL principles

are enacted through the P&PD learning trajectory and embedded in everyday learning activities.

1.2 SDL in the context of the TU/e ID programme

At TU/e, we operationalised SDL through:

- *Autonomous motivation.* Encouraging students to set personal learning goals, fostering intrinsic motivation.
- *Learning beliefs and strategies.* Developing metacognitive awareness and effective learning strategies by supporting students in iteratively shaping their professional identity, design vision, and personal development plans in relation to societal, environmental, and technological contexts.
- *Initiative and perseverance.* Fostering a proactive and resilient mindset through iterative personal development planning and reflection on challenges and achievements.

These elements align with professional commitment and lifelong learning competencies and support autonomous motivation, learning beliefs, and perseverance. The TU/e ID curriculum fosters these competencies through challenge-based projects, interdisciplinary collaboration, and reflective practices that promote self-assessment and continuous improvement.

1.3 SDL in the context of the TU/e Bachelor College

In the pursuit of educating engineers for the future, the TU/e Bachelor College (BC) led the redesign of its bachelor programmes in 2022-23. The TU/e BC is the umbrella structure for all TU/e bachelor's programmes. It was designed to educate 'future-proof engineers' who can address societal and technological challenges while having flexibility in their academic development and give students a solid engineering foundation while allowing them to tailor part of their curriculum to their own interests and career goals. The design principles were guided by the college and institutional directives, which placed an emphasis on the development of a Professional and Personal Development (P&PD) learning trajectory to deliver responsible and 'future-proof' engineers. All TU/e bachelor programmes have been redesigned to integrate the BC core elements as set out in the directives. However, the inclusion of P&PD in each programme followed a 'diversity-by-design' approach to encourage contextual and programme-specific embedding in the curriculum.

SDL was approached at TU/e and is recommended as being embedded within the broader educational ecosystems and lifelong learning environments at TU/e and therefore should not be viewed in isolation. At TU/e this meant:

- Just-in-time learning that supports immediate application of knowledge.
- Collaborative learning, where individuals self-direct within teams and communities of practice.
- Critical thinking that enables learners to evaluate strategies, sources, and outcomes.

- Communication skills that facilitate articulation of learning goals and reflective dialogue with peers and mentors.

Together, these elements reflected a paradigm shift from static knowledge acquisition to learning agility, which at TU/e means instilling the capacity to learn, unlearn, and relearn throughout one's career and aptly through a student's learning trajectory.

1.4 Development of SDL in engineering education

The relevance of SDL for future engineers stems from its support for the development of lifelong learning capabilities. Frameworks such as CDIO (Crawley et al., 2014) and the T-shaped engineer model, which combines disciplinary expertise with broad professional and interdisciplinary competencies, emphasize autonomous learning, open-ended problem solving, and collaboration across disciplines and cultures.

In engineering education, student autonomy is systematically embedded in the curriculum and operationalised through five interrelated sub-skills:

1. Goal setting involves defining clear and attainable goals that sustain motivation and align personal interests with professional competencies, ranging from acquiring technical skills to contributing to multidisciplinary design challenges (Christopher et al., 2023).
2. Planning entails identifying learning needs and structuring timelines and activities to achieve learning outcomes. In engineering education, it supports project-based and agile workflows that enable iterative progress and innovation (Li et al., 2023).
3. Self-regulation refers to monitoring and managing learning processes, including time management, strategic adaptation, and emotional resilience. Self-efficacy strongly influences persistence and adaptability in uncertain and failure-prone design contexts (Stofiana et al., 2025).
4. Reflection promotes learning through critical evaluation of experiences and decisions, supporting conceptual understanding and ethical awareness, particularly in design and sustainability contexts (Christopher et al., 2023; Jackson, 2025).
5. Professional identity and vision enable learners to connect current learning to long-term professional aspirations by developing a sense of direction, values, and self-concept as engineers, fostering lifelong learning and adaptability (Dehing et al., 2013; Trevelyan, 2014).

2 The significance of SDL in the ID bachelor programme: redesigning SDL into the professional and personal development (P&PD) learning trajectory

In response to these challenges and following the Bachelor College curriculum redesign initiative in 2022 (Gómez-Puente et al., 2020), the ID programme integrated a mandatory, longitudinal Professional and Personal Development (P&PD) learning trajectory. This redesign reflects a university-wide shift toward competence-based, student-centred education, with a strong emphasis on SDL, reflective practice, and

professional identity development. SDL activities complement the P&PD learning line by supporting students in goal setting, continuous feedback, and coaching, and the development of adaptive expertise needed in interdisciplinary engineering contexts.

The redesign of the ID bachelor curriculum at TU/e took place in 2023 and was guided by van den Akker's curriculum spider web model, which shows that educational elements such as objectives, assessment, teachers' role and alike are interconnected with each other in a curriculum (van den Akker, 2003), Bloom's taxonomy, and constructive alignment principles (Biggs et al., 2022). The aim was to scaffold students' metacognitive growth from basic reflection toward independent goal setting and professional identity formation. SDL was embedded in the P&PD learning trajectory to support the development of transferable competencies and skills that are not tied to a specific discipline or role but are essential in dynamic professional environments. These include goal setting, personal development planning, self-regulation, collaboration, reflection, and the development of Professional Identity and Vision (PI&V). Learning objectives and assessment rubrics for P&PD were aligned primarily with the first three levels of Bloom's taxonomy (Remember, Understand, Apply).

Across the three programme years, the P&PD learning trajectory supports a progressive development of PI&V:

- In Year 1, students articulate their emerging PI&V based on learning activities and outcomes.
- In Year 2, students explain relationships between competencies while further developing their PI&V.
- In Year 3, students use their PI&V to guide competence development plans for their final bachelor projects and beyond.

The P&PD learning trajectory was co-designed through department-wide education days involving students, staff, educational developers, and the Education Management Team. The learning trajectory includes lectures on competence-centred learning and SDL, peer mentoring, skills-focused training sessions (e.g., planning, teamwork, information literacy, and project pitching), and coaching sessions for reflection and feedback. In addition, students complete assignments related to SDL sub-skills. Educators, student mentors, and coaches (academic staff that coach project teams) fulfil complementary roles, together providing structured P&PD learning experiences alongside the disciplinary curriculum of the ID bachelor programme.

3 Curriculum innovation and change management for self-directed learning at TU/e ID

The integration of SDL within the TU/e ID curriculum has been realised through a long-term process of curriculum innovation and change management. Rather than introducing SDL at the level of individual modules, the department deliberately embedded it as a guiding principle across the curriculum, requiring alignment between institutional vision, educational strategy, and everyday teaching practices.

This process can be understood through Kotter's (2012) change management framework. A shared sense of urgency was created by articulating a clear vision of the designer as a reflective and autonomous professional. A guiding coalition of educational leaders and faculty members translated this vision into curriculum reforms, supported by iterative pilots that served as short term wins and built momentum for broader implementation.

Over time, SDL became structurally embedded through curriculum reviews, coaching practices, and the P&PD learning trajectory. These mechanisms ensured that student autonomy was sustained beyond individual initiatives. At the same time, embedding SDL remains an ongoing process that requires continuous attention to evolving educational and societal contexts.

3.1 Alignment with university vision on education

TU/e has articulated a university vision of educating 'engineers of the future', i.e., graduates who are self-directed learners capable of making informed choices and taking responsibility for their development (Eindhoven University of Technology, 2023). In the ID department, this vision is operationalised through the integration of SDL into the curriculum, positioning students as active agents in shaping their own learning journeys. SDL is not treated as an isolated skill but as a competence that permeates all aspects of the programme, connecting design practice, reflection, and personal growth (Knowles, 1975; Zimmerman, 2002).

The P&PD programme across the university has been closely tied to the development of SDL within the ID curriculum and can be used as a framework for competence-centred learning and self-reflection. The ID department has aligned its educational vision and strategy with this programme, embedding SDL into a dedicated P&PD learning trajectory that runs across the bachelor curriculum. Through this integration, students are continuously encouraged to articulate personal goals, reflect on progress, and connect their professional identity development with broader academic and societal challenges (Garrison, 1997).

Stakeholder redesign

The redesign resulted from a co-creative, participatory effort involving a wide range of stakeholders. In line with the official Bachelor College redesign guidelines, the Programme Committee and Student Council, comprising staff and student representatives from different years of the bachelor programme, were involved, together with the Education Management Team (EMT), responsible for curriculum implementation, and the Department Board, overseeing educational innovation, to ensure both academic rigour and a student-centred approach.

Following an initial problem analysis phase, a shared set of design principles for the SDL learning trajectory was formulated and iteratively refined through stakeholder workshops at education days, consultations with various educational committees and student representatives, and quality assurance activities along the implementation process. These principles guided decision making throughout the redesign and ensured alignment across modules and academic years.

Operationalizing SDL

A key challenge in curriculum innovation is translating strategic intentions into coherent educational practice. Within the TU/e ID programme, this required deliberate alignment between educational vision, curriculum design, and operational practices. Coaches and mentors played a central role in supporting students' SDL development, while programme leaders ensure alignment through feedback mechanisms, reflective tools, and structured training activities. Sustaining this alignment involves continuous staff development, evaluation, and iterative refinement.

The curriculum redesign was guided by the principle of 'high alignment, high autonomy', which balances institutional coherence with flexibility at programme and student level. Within this framework, students are given substantial autonomy to direct their learning trajectories, while shared learning outcomes ensure curricular consistency (Binkley et al., 2012). This balance enables diverse learning pathways while maintaining educational quality.

Complementing this principle, 'diversity by design' underpins the department's approach to SDL. Students engage in varied activities, such as design projects, prototyping, research, reflection, and interdisciplinary collaboration, that reflect the multifaceted nature of industrial design practice and provide multiple opportunities to develop SDL competencies through choice and reflection (Gómez Puente et al., 2020).

As a result, SDL at ID is structured around recurring cycles of goal setting, action, feedback, and reflection through the bachelor program. Large-group lectures introduce shared language and frameworks on PI&V, reflection, ethics, expertise development, and portfolio building. These are systematically connected to small-scale student mentor meetings, where students work in consistent groups to translate concepts into PDPs, PI&V, and reflection.

The operationalisation of SDL takes place in a deliberate sequence. In the first year of implementation, student mentoring structures and reflective assignments are designed to support guided goal setting and reflection. In subsequent years, responsibility is progressively shifted to students through freer assignment formats and increased choice in learning activities. Concurrently, coaching roles are redefined to support long-term developmental guidance rather than short-term task supervision.

Individualisation is ensured through regular coach meetings, providing tailored feedback on students' PI&V, competence development, and study choices over time. Skills trainings (e.g., feedback, planning, collaboration, pitching) operationalise professional behaviour through practice rather than abstraction.

Assessment is predominantly formative and portfolio-based, with multiple low-stakes assignments, reflective deadlines, and iterative portfolio updates. The progression from guided reflections to structured assignment cycles, and to portfolio-driven and future-oriented development show a deliberate scaffolding of autonomy. Overall, SDL at ID is enacted as a continuous, mentored professional learning trajectory, tightly embedded in students' education rather than treated as a stand-alone subject.

3.2 P&PD Year 1 development and learning trajectory design

P&PD Year 1 functions as the foundational basis of the P&PD learning trajectory, explicitly designed to introduce first year ID students to structured self-directed learning through a carefully scaffolded trajectory. The development is visible in the sequenced integration of instruction, guided practice, feedback, and increasing learner autonomy, distributed across the academic year.

Orientation and shared terminologies

The year opens with a kick-off lecture on PI&V, immediately positioning personal development as a legitimate and assessable domain of learning. Lectures on documenting process and reflecting at the beginning establish a shared conceptual vocabulary that students will use throughout the year.

Guided socialisation through mentoring

A central element of the trajectory is the recurring bi-weekly student mentor meetings (eight in total). These meetings are deliberately interleaved with lectures and focus on:

- Drafting a PDP;
- Articulating PI&V and future orientation;
- Reflecting on disciplinary knowledge;
- Developing and reviewing a draft portfolio;
- Making informed study choices for Year 2.

Working in stable small groups, students externalise reflection and learn professional dialogue before being expected to be self-regulated more independently.

Individualisation via coaching

Five coach meetings, scheduled at pivotal moments, support individual sense making and developmental steering. These meetings operationalise individualisation by explicitly addressing competence development, PI&V coherence, and learning choices over time rather than discrete module deliverables.

Competencies and skills training as behavioural enactment

Four targeted training sessions (feedback, planning & organising, collaboration, pitching) translate reflective intentions into observable professional behaviour. Their placement after key reflective moments ensures competencies and skills are learned in response to perceived developmental needs.

Formative assessment and autonomy scaffolding

The assessment is embedded through two major reflective deliverables: a reflection mid-year and a portfolio at the end of Quarter 3. The trajectory moves from guided reflection toward portfolio-based synthesis, preparing students for greater autonomy in subsequent P&PD modules.

In summary, P&PD Year 1 is deliberately developed as a high-support, high-structure entry point into SDL. Through repetition, variation, and strategically timed feedback

moments, it establishes the habits, language, and reflective competence required for progressively self-directed professional learning in the following years.

4 Case study: scaffolding students' development in SDL competencies

Central to the development of students' autonomy competencies especially for first-year students is the guidance to become self-directed learners, which we explain in steps. Our students come from very diverse socio-economic and cultural backgrounds, not only from the Netherlands but from all over the world, with a slightly higher number of male than female students. Therefore, training students in professional identity and vision and reflection are core elements of the programme.

In our case study, we show how coaching meetings, assignments, and peer feedback are purposely employed as educational elements aiming at scaffolding the SDL competence development. In addition, through the university Learning Management System (LMS), Canvas, students get access to all the assignments that provide assistance in the content, requirements, and deadlines of the activities. In Example 1, we show how we define one of the assignments, the Personal Development Plan.

Example 1. Personal Development Plan

The Personal Development Plan (PDP) is a framework to support your development. It is a document for planning and directing your competency development on a continuous level, by formulating goals based on your reflection on learning experiences. Formulating goals provides your learning with a direction and makes it possible to evaluate and monitor your progress towards your goals.

The idea is that you use the PDP as a tool to direct your long-term development through formulating a vision on designing (what kind of designer you want to become) and short-term development, describing what do you want to achieve per learning activity. Therefore, you write and adjust your PDP before each coach/mentor meeting in which your study planning and future career is addressed.

A PDP is not a fixed document; you change it along with your development. The deadline in the Canvas assignment is a guideline to support you in guiding your development and prepare your PI&V coach and mentor meetings. You can upload and update your document multiple times during the semester.

TU/e organises its academic year into two semesters, each subdivided into two teaching quarters with distinct module periods and examination blocks, meaning students follow four quarters of modules per year within a semester-based calendar. TU/e ID students need to make choices in Year 2 and 3 based on their own ambition regarding elective modules as well as the Thematic Learning Areas (TLAs) offered at TU/e which allows students to select a set of modules related to a single theme, which, when combined, are part of the self-defined programme of each individual student. TU/e students typically register for modules for Quarter 1 and 2 in late August; registration for Quarter 3 and 4 opens in mid-November. We defined assignments to

support students in choosing their modules. For example, the assignment in Example 2 aims to support students in making choices. The assignments are discussed in groups with the student mentors, so that additional guidance and feedback can be provided.

Example 2. Making choices for Year 2

Goal: make a plan on how to approach making choices for Year 2.

Instructions: prepare a mind map in which you give an overview of the choices you have to make for Year 2. Use the education guide as a source, as well as Canvas, and any other sources you prefer. Make an overview of all the choices that are open to you (that you know of), and what your own choices will likely be (or what you are still doubting between). Why?

Upload the mind map and the overview for this assignment and be prepared to discuss it during the meeting with your student mentor.

Table 4.5.1: Rubrics examples on Reflection on Collaboration for students to self-assess and to receive mentor feedback and summative assessment

<i>Rubrics</i>	<i>Excellent</i>	<i>Good</i>	<i>Sufficient</i>	<i>Insufficient</i>
<i>Reflection on collaboration (individual)</i>	In the portfolio, the student reflects on and evaluates their collaboration with peers and external stakeholders (e.g., users, clients, experts). Using examples from Year 1, they assess their contributions, incorporate feedback, and identify areas for improvement.	In the portfolio, the student reflects on their collaboration with peers and external stakeholders, using Year 1 examples to assess their contributions and incorporate feedback.	In the portfolio, the student describes collaboration with peers and external stakeholders, incorporating feedback, but finds it challenging to clearly articulate their own contributions to the learning activities.	In the portfolio, the student does not describe collaboration with peers or external stakeholders, nor their own contributions to the related learning activities, despite the guidance provided.

Finally, in our case study, rubrics also play a prominent role in stimulating SDL. In our case, rubrics serve as a critical instrument not only for summative assessment, but also as a tool for self-assessment and peer feedback, enabling students to monitor and evaluate the development of their own competencies. Table 4.5.1 lists a rubric example on how to reflect on collaboration in Year 1. Beyond student use, rubrics are also employed by mentors, who provide regular feedback on students' progress, and by coaches, who use them to deliver formative feedback that guides further improvement. In this way, rubrics function as a multifaceted assessment framework that supports both evaluation and learning, fostering transparency in expectations and encouraging continuous development of competencies and skills.

5 Evaluation of Year 1

To examine the impact of the P&PD learning trajectory on students' perceptions of SDL, a mixed methods study was conducted among all 159 first year students enrolled in the ID bachelor programme during the 2023-2024 academic year consisting of a survey, focus groups, and semi-structured interviews. The study analysed the P&PD learning trajectory using the curriculum landscape typology (van den Akker, 2003), who distinguishes between three types of curricula: the intended curriculum (what the programme intended to teach), the implemented curriculum (what was actually taught), and the attained curriculum (what students actually learned).

As input for the study, the intended curriculum, as envisioned by the staff, was established through a semi-structured interview, conducted with the programme director, focusing on the vision and objectives of the P&PD learning line. To discover the implemented curriculum interviews with coaches and mentors, complemented by two student focus groups were carried out. The attained curriculum was primarily assessed through a student survey and focus groups, capturing perceived learning gains related to SDL.

The results showed that from the programme management perspective, the intended curriculum aims to develop SDL as a core outcome. Integrated tools and practices have increased students' confidence and readiness for Year 2, although strengthening coherence between content and assignments remains an area for further improvement.

With regards to the implemented curriculum, during the interviews with coaches and student mentors, coaches observed that students are motivated to develop SDL skills but continue to require guidance to sustain their learning. Tools such as portfolios, feedback, rubrics, and reflective activities support this process, although students often need help maintaining an overview of their development. Student mentors indicated that reflection and feedback support self-monitoring and awareness, particularly when links between assignments and programme goals are made explicit. Group coaching stimulates reflection on professional identity, yet first-year students still struggle with articulating this identity, as well as with goal setting and planning, which require continued support.

The survey to establish the attained curriculum combined closed and open-ended questions. Using a standardised instrument, students evaluated training activities across five dimensions: engagement, organisation, feedback, learning atmosphere, and perceived learning gains (five-point Likert scale). Overall satisfaction was rated on a ten-point scale. Open-ended responses on strengths and areas for improvement, together with interview and focus group data, were analysed across the three curriculum levels to provide an integrated understanding of SDL development in the first year of the programme.

In order to explore the students' perceptions of SDL in this part of the study (attained curriculum) in more detail, two student focus groups were conducted to explore experiences and perceptions related to SDL and its key subskills: goal setting, planning, reflection, self-monitoring, and professional identity and vision. The discussions revealed both strengths and areas for improvement in how these competencies and skills are supported within the curriculum. The key themes of student feedback on the attained curriculum are summarised in Table 4.5.2.

Table 4.5.2 Summary of student survey and focus group results

<i>Theme</i>	<i>Positive points</i>	<i>Areas for improvement</i>
<i>Goal setting</i>	Tools and feedback support goal setting; reflection and questioning help connect assignments and learning goals.	Difficulty translating broad objectives into concrete goals; need for clearer guidance and balance between autonomy and coaching.
<i>Planning</i>	Practical tools and templates help structure planning.	Planning seen as challenging and sometimes disconnected from project work; more early support needed.
<i>Reflection</i>	Portfolio writing and templates stimulate reflection on learning.	Purpose of reflection not always clear; need for earlier introduction, clearer framing, and examples.
<i>Self-monitoring</i>	Feedback and alignment between assignments, competencies, and skills support awareness over time.	Students feel underprepared for ownership early on; gradual increase in coaching and feedback needed.
<i>Professional Identity and Vision</i>	Activities for self-exploration and peer learning are valued.	Difficult to articulate identity early in the programme; need more real-world exposure and role models.

Students stressed the importance of a safe and supportive learning environment for developing SDL skills and expressed a desire for greater flexibility and personalisation in their learning paths. They also noted the need for better integration between lectures, coaching, and mentoring.

Implications for further development of SDL

This analysis suggests that while some learning activities effectively support SDL, particularly in later stages, others require redesign to better activate student engagement and skill development. The progression in perceived value aligns with the broader trend observed in the PI&V learning trajectory: students recognise the importance of these competencies more clearly as they advance in their studies. This suggests a new iteration is needed in the design to improve the different SDL element.

6 Synthesis, implications, and conclusions

This chapter examined how SDL has been embedded within the ID bachelor programme at TU/e through curriculum innovation, with particular attention to the P&PD learning trajectory. Using multiple data sources, student surveys, focus groups, and interviews with coaches, mentors, and programme leadership, the study explored how SDL is intended, implemented, and experienced in practice.

Overall, findings indicate that students recognise the value of SDL and its underlying competencies, including goal setting, planning, reflection, self-monitoring, and professional identity development. However, students consistently emphasised the need for earlier exposure, stronger scaffolding, and better integration of SDL practices across modules, projects, and learning activities. SDL development was most effective when learning activities were clearly connected to assignments and professional goals, supported by timely feedback and opportunities for reflection.

From an implementation perspective, the P&PD learning trajectory plays a critical role in operationalising SDL at curriculum level. Coaches and mentors were essential in guiding students' learning processes, particularly during the early stages when students struggled to articulate goals, plan their learning, and reflect meaningfully on their development. Tools such as portfolios, reflection templates, feedback rubrics, and structured coaching conversations supported SDL development, yet students often need continued support to maintain an overview of their learning progress and to connect individual activities into a coherent developmental trajectory.

A central insight from this study is the importance of balancing structure and autonomy. The ID curriculum design follows a principle of high alignment with institutional goals while granting students significant autonomy to make meaningful choices. Students benefit when expectations are clear yet flexible, allowing them to experiment, revise, and gradually assume responsibility for their learning. Likewise, the principle of 'diversity by design' (As explained in Chapter 3.7) enables multiple learning pathways while maintaining shared programme goals, accommodating the varied interests and learning needs inherent in design education.

Looking ahead, continuous curriculum development remains essential. Future efforts at TU/e ID focus on strengthening longitudinal integration of SDL across the curriculum, increasing coherence between projects, coaching, and assessment practices, and enhancing professional identity development through authentic engagement with industry, societal challenges, and role models. Further refinement of reflective practices, clearer framing of learning objectives, and sustained professional development for coaches will support this ongoing evolution.

In conclusion, developing SDL in engineering education requires more than isolated training activities or standalone tools. It demands a whole-curriculum approach in which SDL competencies are introduced early, reinforced through authentic learning experiences, and supported by consistent coaching and feedback. The experience of the TU/e ID programme demonstrates that when SDL is embedded structurally, through curriculum design, professional development, and change management, students are better prepared to guide their own learning, adapt to complexity, and engage in lifelong professional growth.

7 Key takeaways for practitioners

If you were to set out on a similar journey, we would recommend to:

- introduce goal setting from week 1 using simple SMART style templates students can personalise over time;
- integrate planning directly into project meetings and design reviews so it becomes part of normal engineering workflow;
- use the same rubric for assessment and student self-reflection to reinforce coherence and shared expectations;
- schedule individual or small group coaching sessions every 4 weeks to support autonomy and metacognitive growth;
- provide multiple pathways for SDL development, through varied projects, mentoring, and flexible reflection formats;
- encourage psychological safety by normalising iteration and emphasising reasoning rather than correctness in feedback;
- offer visual summary tables or infographics that break SDL down into subskills (e.g., goal setting, monitoring, reflection) and show concrete ways to apply each in teaching practice.

Within the SEFI handbook framework, the competencies addressed in this chapter align primarily with the category of lifelong learning. The emphasis on self-directed learning, reflection, goal setting, and professional identity development directly supports graduates' capacity to continuously update their knowledge, competencies, and skills throughout their careers. In addition, elements of the P&PD learning trajectory contribute to related transversal competencies, such as self-management, communication, and professional responsibility, illustrating the interconnected nature of these competencies and skills in contemporary engineering education.

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AI statement

During the preparation of this work, the authors used Microsoft Copilot in order to improve the quality of writing in English and rephrase paragraphs. After using Microsoft Copilot, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

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4.6

Integrated Engineering at University College London: Embedding Transferable Skills using PBL, Illustrated by the Biomedical Engineering Degree Programme

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The Integrated Engineering Programme (IEP) at University College London (UCL) was designed to make the development and assessment of transferable skills and competencies — such as teamwork and communication — an explicit and embedded part of the engineering curriculum. Recognising that these skills are best learned through experience, the IEP integrates them from the first term of the first year of undergraduate studies. This chapter describes the approach taken when embedding transferable skills into the engineering curriculum using problem-based learning (PBL). The latter sections illustrate how the department of Biomedical Engineering makes use of the IEP framework in early years of study and further builds upon the framework in later years of the degree programme. It should be noted that whilst Biomedical Engineering is discussed in this chapter, the application of the IEP framework applies to most of the undergraduate degree programmes at UCL Engineering and thus this chapter is written to be relatable to any engineering discipline looking to embed transferable competencies and skills into their curriculum.

1 Introduction

There is a growing imperative to explicitly embed transferable skills within engineering curricula to meet evolving industry demands and global challenges. The AHEP4 framework and the World Economic Forum's *Future of Jobs Report* identify skills such as analytical thinking, adaptability, communication, teamwork, and ethical reasoning as critical for employability and innovation (World Economic Forum, 2025). These are increasingly valued alongside technical expertise. Addressing complex challenges like sustainability also requires competencies listed by UNESCO, including systems thinking, anticipatory reasoning, and integrated problem solving (UNESCO, n.d.). Such skills enable engineers to collaborate across disciplines, engage stakeholders, and design socially and environmentally responsible solutions. Embedding these competencies prepares graduates to navigate uncertainty, drive change, and contribute to sustainable development, reinforcing that engineering is both technical and societal.

Transferable skills development must be continuous and embedded throughout the degree, rather than treated as a one-off intervention. Skills such as communication, teamwork, ethical reasoning, and systems thinking require repeated practice in varied contexts to become meaningful and transferable. Embedding these opportunities across modules (including design projects, laboratories, interdisciplinary collaborations, and reflective assessments) supports deeper learning and application in real-world scenarios. This ensures such skills are integral to engineering identity and professional readiness.

Real-world problems, including climate change and global health, do not respect disciplinary boundaries. Embedding interdisciplinarity is therefore essential. Integrating perspectives from fields such as social sciences, business, design, and environmental studies fosters broader thinking and innovation. At UCL Engineering, interdisciplinarity is supported through problem-based learning (PBL), where students engage in identifying problems, designing solutions, and applying engineering principles collaboratively.

The Integrated Engineering Programme (IEP), introduced in 2014, catalysed curriculum transformation at UCL by embedding a shared educational vision centred on PBL, interdisciplinary learning, and transferable skills. Core modules and module components include 'Engineering Challenges', 'How to Change the World', and team-based 'scenarios', providing scaffolded opportunities for students to engage with global challenges and collaborate across disciplines. This structure promotes coherence, innovation, and graduate preparedness, while fostering pedagogical collaboration. The IEP has positioned UCL Engineering as a leader in curriculum reform (Graham, 2017).

Importantly, the IEP functions *not* as a traditional degree programme but as a pedagogic framework mapped across programmes. This enables consistency in skills-based teaching while supporting interdisciplinarity. It is coordinated by a central core IEP team to ensure alignment across departments.

This chapter examines how the IEP enables the embedding of transferable (professional) competencies and skills at curriculum level. It outlines the rationale for explicit skills development and presents a case study of the UCL Biomedical Engineering programme, developed alongside the IEP, demonstrating integrated delivery of technical and transferable competencies.

2 Institutional context and need

University College London (UCL) is a world-class, research-intensive university, founded in 1826, with a significant global presence. As of 2025, UCL hosts over 51,000 students from 150 different countries and employs more than 17,000 staff of which over 4000 are academic and teaching staff. The institution comprises of 11 faculties, including the Faculty of Engineering Sciences which includes 10 academic departments: Biochemical Engineering, Chemical Engineering, Civil, Environmental & Geomatic Engineering, Computer Science, Electronic & Electrical Engineering, Mechanical Engineering, Medical Physics and Biomedical Engineering, Science, Technology, Engineering and Public Policy (STEaPP), Security and Crime Science and the School of Management.

Most departments have at least two variations of their undergraduate programme: a 3-year programme (usually denoted as either a BEng — Bachelor of Engineering or BSc — Bachelor of Science) and a 4-year integrated master programme (MEng — Master of Engineering), all EQF level 7, where the first 3 years are the same as the aforementioned BEng or BSc. Each academic year comprises of three terms (or semesters), each 10 weeks long, sandwiched between Christmas and Easter breaks. Terms 1 and 2 contain the bulk of teaching and term 3 is traditionally used for exams. In the first year of a typical BEng/MEng programme, terms 1 and 2 consist of four 15-ECTS modules each.

The motivations for radical curriculum change within UCL Engineering, leading to the Integrated Engineering Programme (IEP), stemmed largely from a perceived skills gap (Mitchell & Tilley, 2024). It sought to address the lack of interdisciplinarity in the curriculum at the time, meaning that each engineering programme was taught mostly in isolation. The aim was to develop a new generation of engineering graduates who were technically skilled, and ready to effectively transition into employment and become the progressive engineering leaders of the future, which required the acquisition of transferable competencies. This focus on a broader skillset aligns with ongoing discussions and policy projects, such as the Royal Academy of Engineering's 'Engineer 2030' initiative, which explores the future skills needs of engineers (Royal Academy of Engineering, 2025).

The implementation of the IEP involved a major revision of teaching and learning practices undertaken over three years before its launch in 2014. It was a cross-Faculty process, built on input from academics across various disciplines and while the concept was driven top-down, the implementation was largely from a bottom-up approach. In its implementation, a team of experienced teaching academics was assembled, supported by a small number of external hires who brought complementary skills and

insight to the development. This process fostered a cultural change across the faculty, shifting the focus from teaching purely technical content to integrating project activities and skills development. and as of 2026, the IEP has formally integrated into the curriculum of 8 departments across the faculty (see Fig. 4.6.1).

3 Curriculum design

3.1 Introduction of a new engineering educational approach: the IEP

The IEP, as delivered at undergraduate programme level, consists of three core modules in year 1, two departmentally-led modules in year 2, a design challenge at the end of year 2 (that counts towards the year 3 capstone project) and a curated choice of elective modules taken in years 2 and 3, known as IEP minors. The IEP framework primarily sits within the first two years of the UCL Engineering degree programmes as this is where the majority of the commonalities across disciplines are. However, the educational philosophy behind the IEP has been adapted and adopted on engineering programmes beyond the first two years, as seen in this chapter within the Biomedical Engineering programme. The structure of the IEP framework and how it sits across the multiple Engineering programmes at UCL can be seen in Fig. 4.6.1. Each of these components is described below.

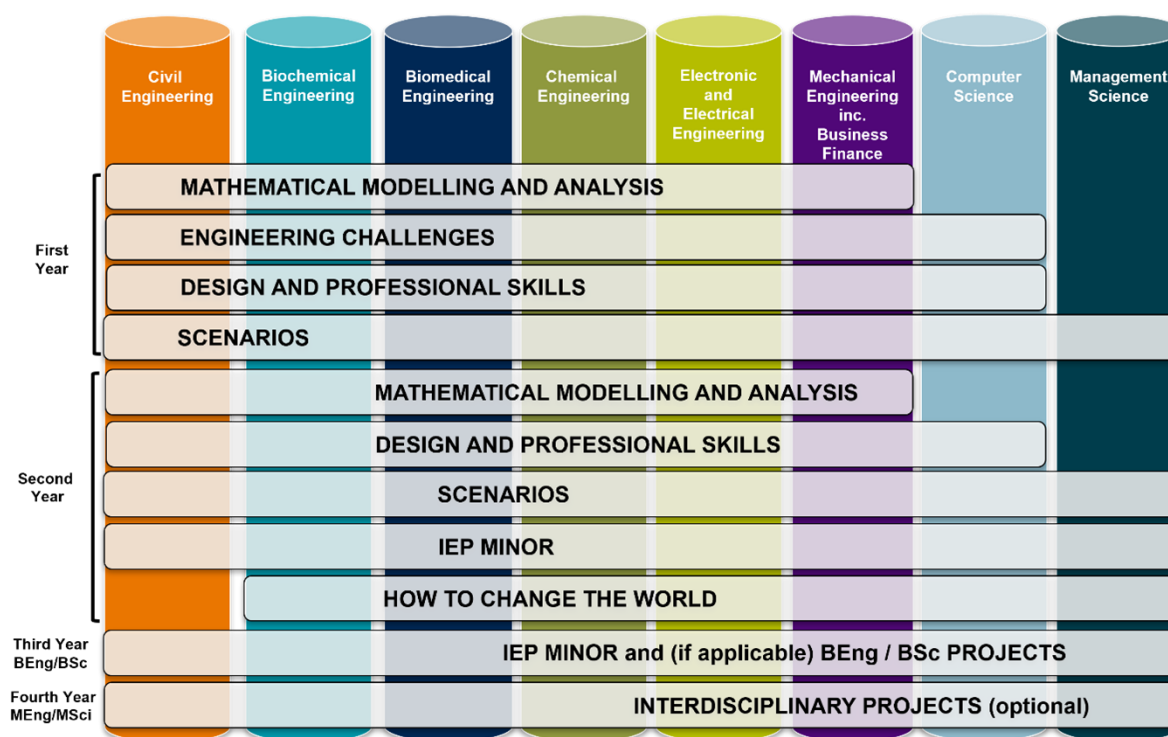


Figure 4.6.1: IEP structure (simplified) (University College London, n.d.)
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Example 1. Design and professional skills module in year 1 term 1 (D&PS1)

This is a module co-ordinated by the IEP core team who sit at faculty level and delivered by departmental teaching teams. The module framework is split into 3 elements: Technical communications (worth 40% where written and verbal communication skills are developed), discipline specific (worth 20%) and 2 scenarios (worth 20% each), spanning across 6 departments. The goal of the module is to embed transferable competencies and skills early in the undergraduate experience, and ensuring students develop a holistic understanding of engineering as a socially aware and creative discipline. The module introduces students to core design methodologies (Fig. 4.6.2) that are tailored to discipline-specific needs such as, the use of AutoCAD for piping and instrumentation diagrams for Biochemical Engineers or programming Arduino for Electronic and Electrical Engineers. The module also integrates professional skills such as project management, reflective practice, and ethical reasoning while explicitly teaching professional skills like communication, teamwork and ethics across all the UCL Engineering disciplines.

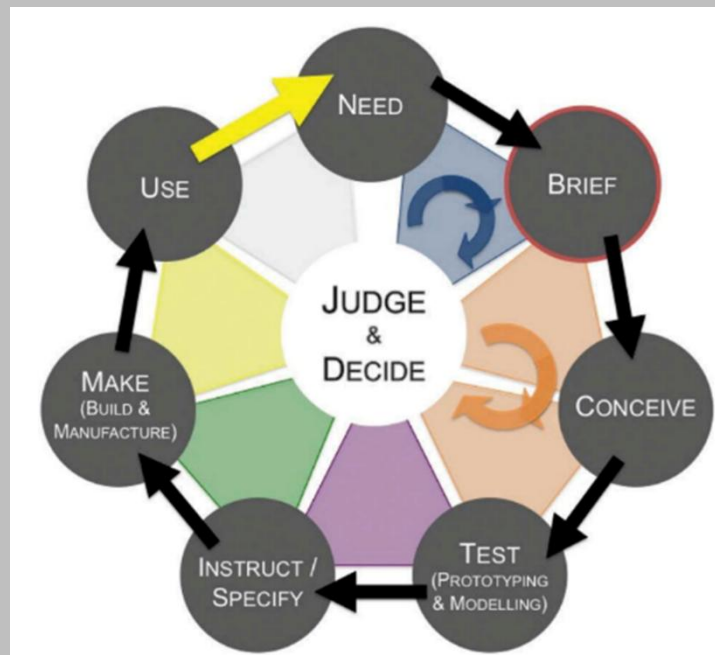


*Figure 4.6.2 Own work: The Design Cycle
(Mitchell et al., 2021 p.7)*

Example 2. The Engineering Challenges (EC) module in Year 1, term 1

This module is an introduction for students to projects and teamworking and is led by the IEP central team with classroom teaching delivered by departments. It is an experiential, PBL module taken by 7 departments across the faculty from the first week of year 1 studies throughout the first term. It consists of two separate disciplinary and interdisciplinary challenges, the first of which takes place in the first 3 weeks of term, whilst the interdisciplinary challenge takes place in the subsequent

7 weeks of term. During the interdisciplinary challenge, student teams design solutions to a real-world problem, making use of all elements of the design cycle (Fig. 4.6.2).

The D&PS1 and EC modules are highly linked in a just-in-time approach. The two modules run alongside each other, so students are taught about certain competencies that they need to put in place in practical projects, then they experience them, and then they are guided through reflection. The aim of the integration between these modules is to avoid dropping students into a situation and hoping that they will learn the skills they need but rather support and guide them. Sessions are carefully linked, with a skill discussed in class in DPS1 one week and then used within EC the next week; this just-in-time approach means that students have a basic grounding in a skill before they attempt to use it within a project but they are not learning so far ahead that they forget the grounding before they are able to use it in context.

Example 3. Scenarios across Years 1 and 2

Scenarios are week-long intensive group projects embedded within D&PS1 and D&PS2 but delivered by individual departments. Students complete two scenarios in Year 1 (Term 2) and four scenarios in Year 2. These activities follow a repeating five-week cycle: four weeks of conventional teaching are followed by a one-week intensive project. This structure is intentionally designed to connect theoretical learning with practical application, enabling students to engage deeply with authentic engineering challenges in a concentrated timeframe.

While all scenario weeks are centred on the design process, the projects become progressively more complex across the programme and increasingly require the creation of tangible outputs. The production of physical artefacts enhances the realism of the learning experience and provides a valuable form of authentic assessment.

Scenario styles vary, but the majority align with established models of problem-based learning that emphasise critical thinking, evaluative judgement, and analytical reasoning. Drawing on frameworks by Kolmos et al. (2009) — building on the work of Savin-Baden (2000) — these projects go beyond straightforward application of taught material. Instead, students engage with open-ended that demand thoughtful evaluation and synthesis of ideas.

The introduction of scenarios is a key innovation in the IEP framework, promoting the benefits of scenario-based learning, where students tackle open-ended problems contextualised within societal or industrial settings. This approach fosters creativity, resilience, and adaptability-skills essential for future engineers.

Design and Professional Skills (D&PS2): This is an extension of D&PS1, run in year 2 by departments. The module continues the thread of applied and practical

implementation of skills learning but now tailoring it to specific skills that are most relevant to the individual engineering discipline.

How to Change the World (HtCtW): This is a two-week intensive, interdisciplinary team-based design challenge centred around the UN's Sustainable Development goals. It often involves industry and government clients, aimed at tackling socially-based global problems and exposing the students to different stakeholders. This activity takes place in term 3 of year 2 (after exams) and feeds into departmentally-led 3rd year capstone projects.

IEP Minors: The IEP framework also aims to give students the opportunity to learn about an engineering field or topic outside their discipline, or deep dive into a particular area of their speciality. Students do this by taking an IEP minor, consisting of a stream of three connected modules, allowing students to customize their degree.

Mathematical Modelling and Analysis 1 and 2 (MMA1 and MMA2): These modules focus on the development of mathematical skills, both theoretical and applied. A key IEP pedagogical design is that these modules are taught via an applied flipped learning approach with the aim of teaching not just theory but also how to use mathematics within in an engineering context, using examples from across disciplines. The module also features the use of real data and the training of students on how to visualise and analyse that data, which we see as an important component of technical communication. The module taught lectures are led by the faculty and taken by students in many of the UCL Engineering disciplines, while workshops are run at departmental level. Whilst the approach to teaching mathematics forms a key part of the IEP pedagogical design, it is not the focus of this chapter.

It can be seen how the IEP framework strongly emphasises P(j)BL. The flagship real-world, project-based activities start with the Engineering Challenges (two multi-week global engineering projects, one of which is interdisciplinary), continue with the scenarios (six one-week projects done within the discipline) across years 1 and 2 in D&PS 1 and 2, and leads onto the HtCtW (2-weeks interdisciplinary project) at the end of year 2. This thread of project-based activities is the central spine of the integrated curriculum model developed which connects technical instructions and transferable skills development through disciplinary and interdisciplinary projects.

3.2 Implementing the IEP framework in Biomedical Engineering

As mentioned in the Introduction, the Biomedical Engineering programme was selected as it was developed at the same time as the IEP framework, hence incorporating this new philosophy of education from its conception. However, the principles, journey and reflections can be applied to any engineering discipline.

The Biomedical Engineering programmes (Biomed Eng) were developed at the UCL Medical Physics and Biomedical Engineering department, comprising a three-year BEng and a four-year MEng. Their development was a significant change for the department, which was until then almost purely research-focused and only had a few undergraduate students on a shared programme predominantly taught by another department. In acknowledgement of the scale and importance of this change, two

education-focused staff members were recruited to support the design and delivery of the new Biomed Eng programmes. These individuals subsequently became key contributors to the development of the IEP framework and its associated modules. The programme initially launched with a deliberately small intake (12 students) as a pilot. Since then, it has grown into a highly successful and popular offering, reaching an intake of 170 students in the 2025/26 academic year.

From inception, the Biomed Eng programme was structured around four main principles listed in Example 4.

Example 4. Principles of UCL Biomedical Engineering programme development

- Integration of the IEP framework. *Including its focus on PBL, competence learning, and design methodology*
- Progressive skill building. *Founded in the IEP framework but extending to discipline-specific modules across all years and culminating in higher stakes, research-informed projects.*
- Whole programme coherence. *Learning outcomes are intentionally mapped across modules to avoid fragmentation and promoting progressive lines of learning (topics) and skills with numerous references across modules.*
- Authentic assessment for learning. *A deliberate shift toward authentic, coursework rich and varied assessment, using multiple formats of assessment and asking students to address their work to different audiences hence developing different styles of communication.*

Integration of the IEP framework: As the IEP and the Biomed Eng programme were developed in parallel—by overlapping teams with strong pedagogic interests and a shared commitment to coherent, connected, and practically focused, employment-relevant education—the Biomedical Engineering curriculum was designed from the outset to fully embrace the IEP framework and fully integrate PBL, professional skills, and the design methodology. Furthermore, this educational philosophy was extended beyond the IEP-branded modules and permeates the entire programme. This includes many of the so-called technical modules across all years of study (from Year 1 to Year 4).

This progression in the development of skills has recently been more formally articulated through use of the AHEP4 graduated definitions of each learning objectives (e.g., “*Communicate effectively with technical and non-technical audiences*” at first-year level deepening to “*Communicate effectively on complex engineering matters with technical and non-technical audiences, evaluating the effectiveness of the methods used*” at master level).

We assessed our approach and investigated how critical thinking and communication skills were developing across the programme, specifically looking at the effect of three types of activities aimed at teaching these skills, namely (1) practical open-ended group activities; (2) discussion with experts or as experts; and (3) peer assessment.

These methods were assessed in terms of student and staff opinions, but also practicality, and we observed it was beneficial to integrate and balance these three types of activities as they complement each other (Garcia-Souto et al., 2017).

As a department we also led the way in assessing some additional skills within the context of a scenario, and not by additional assignments associated with the taught elements of the module (Yerworth et al., 2017). This practice has now been widely adopted through the IEP affiliated modules. An example of this is interpersonal communication skills — Adaptive Communication Styles. Students are required to write a user guide for the aid-to-independent-living they design in Scenario 6 using the Easy read format (Gov.uk, 2025), a format originally developed by and for people with learning disabilities.

Whole Programme Coherence: A programme-level approach was taken when developing the curriculum, with a high degree of intentional alignment between the modules and learning activities. One way of achieving that coherence was through the roles of subject leads — tasked with maintaining a knowledge of where, in every year and module, their subject manifests, and with influencing, motivating and helping the relevant module leads to nurture and develop the connections between those modules (Yerworth et al., 2018). This led to teaching staff regularly contextualising content by highlighting its upcoming application elsewhere in the programme. It was common for lecturers to explain to students: “*We are covering this material now because you will apply it in [named module] next week.*” This explicit cross referencing strengthened students’ sense of purpose, improved knowledge retention, and reinforced the coherence of the curriculum.

The structure of the Biomed Eng programme resembles a typical engineering degree, with three or four years of study (for BEng and MEng respectively) and typically eight 15-credit modules per year, four taught in October-December, and four others taught in January-March, with final exams in May-June (as outlined in sections 2). The structure of the programme is presented in Fig. 4.6.3 alongside a simplified mapping on where selected competences and skills are taught, developed, and assessed. Modules are colour coded to highlight IEP-branded modules with strong PBL and competence learning (in purple), modules where students develop general mathematical and science knowledge (in blue), technical modules (in green) and capstone project modules (beige). It can be seen how competencies are taught right from the start of the programme, firstly in the IEP-branded modules, but nicely complemented and expanded on within the discipline specific modules across all years, culminating in the Individual Research project in year 3 or the Group design project taken by year 4 MEng students as a capstone, with competences being explicitly or implicitly demonstrated at a more advanced level.

Authentic Assessment for Learning: Integrating a variety of assessment types within a programme enables students to build a broader set of competencies beyond subject-specific knowledge. The modular structure commonly used in UK higher education can often result in an over-reliance on a single assessment format, such as written reports. To address this, we adopted a programme-level perspective, designing and evaluating

a more diverse mix of assessment approaches. These included traditional methods, authentic tasks reflecting workplace practices, research-informed activities, and assessments tailored to different audiences (Gibson et al., 2018).

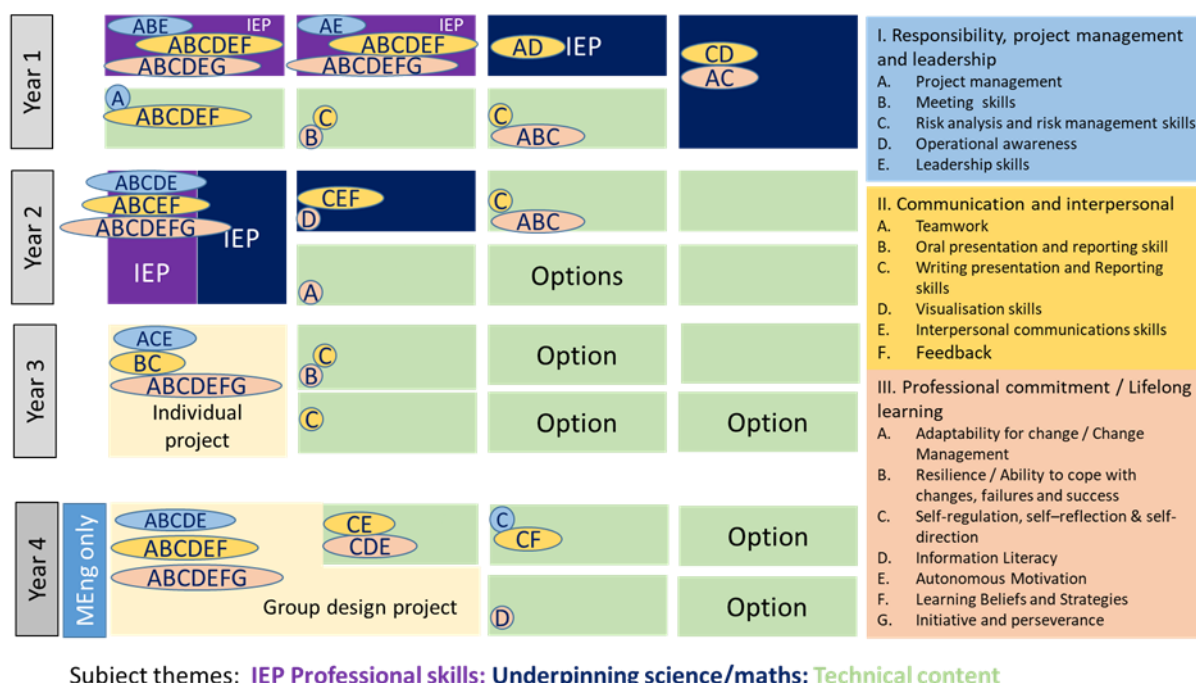


Figure 4.6.3: Biomedical Engineering programme structure with a simplified mapping on where selected competences and skills are taught, developed, and assessed (Own Work by the authors)

4 Bringing it all together: competencies and skills development using PBL

In 2024, Mitchell & Tilley reported on how problem- and more specifically project-based learning is intentionally positioned as the central organising principle through which both disciplinary knowledge and professional competencies are developed. Rather than treating engineering science, design, and skills training as separate instructional streams, curricula built on PBL align these elements within a coherent sequence of authentic, progressively challenging projects. This structural choice enables students to encounter core theoretical concepts at the moment they are needed, creating an iterative interplay between conceptual understanding and practical application (Mitchell & Tilley, 2024).

What this means in our case is that PBL provides a useful pedagogic lens for distinguishing, and effectively relating, skills and competencies within an engineering curriculum. In conventional curricula, skills are often treated as discrete, teachable abilities: for example, report writing, CAD modelling, statistical analysis, or oral presentation. These are typically delivered in isolated modules or workshops and assessed independently of authentic engineering contexts. By contrast, competencies

represent the integrated, context-dependent mobilisation of multiple skills, knowledge, attitudes, and professional judgement to address complex, real-world problems. Competence is therefore demonstrated not by performing a single task, but by demonstrating diverse capabilities (sometimes concurrently) in a coherent and purposeful and authentic manner (Gerstein & Friedman, 2016).

Two of the most studied and most iterated competencies and skills on the IEP are teamwork competencies and communication skills (Nweke, 2021; Nweke et al., 2023, 2025; Truscott et al., 2020; Truscott & Smith, 2025). Here we describe how PBL allows for their development whilst incorporating the technical aspects of the biomedical engineering degree programme on the scenarios.

Example 5. Teamwork development within the IEP framework

Teamwork development through PBL is closely aligned with the aims of Design & Professional Skills 1 (D&PS1), which provides students with an explicit foundation in how to work effectively in teams while they are simultaneously practising these skills in project work on The Engineering Challenges. In D&PS1, students are introduced to core concepts of professional teamwork such as effective communication, role allocation, project planning, inclusive collaboration, and professional conduct. These concepts are framed as practical tools that students are expected to apply directly within their PBL teams, and this is done by ensuring that the two modules run concurrently.

Students then enact and develop these teamwork skills through their PBL project work by actively structuring how their teams operate. They agree team norms and expectations at the start of projects, negotiate roles and responsibilities, and establish routines for meetings and shared decision making, drawing on the frameworks and guidance introduced in D&PS1. As projects progress, students practise professional communication by explaining technical ideas to peers from different disciplinary backgrounds, documenting group decisions, and presenting collective outcomes. When tensions or disagreements arise within teams, students are encouraged to draw on strategies discussed in D&PS1, such as constructive feedback, respectful challenge, and reflective dialogue, to manage conflict and maintain productive collaboration.

Leadership and responsibility are also developed through the interplay between D&PS1 and PBL practice. D&PS1 introduces ideas around shared leadership, ethical professional behaviour, and accountability within teams, which students then experience in practice by rotating coordination roles, taking responsibility for organising aspects of the project, and supporting peers' leadership when they are not leading themselves. This helps students understand leadership as a situational and collaborative process rather than a fixed personal trait, and reinforces professional behaviours such as reliability, responsiveness, and respect for others' contributions.

Reflection provides the link that helps students turn experience into learning. A commonly used tool for reflection (and peer assessment) on the IEP is IPAC (Individual

Peer-Assessment of Contribution to group work (Garcia-Souto et al., 2019, 2024) — see Chapter 3.2 for more details). Through the use of this tool for reflective activities and peer feedback aligned with D&PS1 learning outcomes, students analyse how their teams functioned, how effectively they communicated and collaborated, and how their own behaviour affected the group's performance. This reflection encourages students to connect theoretical models of teamwork introduced in D&PS1 with concrete experiences from their PBL projects, enabling them to identify specific areas for improvement and to apply these insights in subsequent team-based tasks. The students also receive peer feedback on how their contribution was perceived by their peers, so they can reflect on the effectiveness of their approach. Over time, this tight coupling between explicit skills teaching in D&PS1 and repeated practice in PBL supports the progressive development of teamwork competencies that are central to professional engineering practice.

Example 6. Communication development within the IEP framework

Communication on the IEP begins with the ability to articulate technical reasoning clearly to peers on the Challenges, through short peer-assessed videos that students create. An example of this in the Biomedical Engineering context would be "Describe a medical technology that most interests you and how you would apply this technology to UCL Grand Challenges". Students are then taken through how to define their research question, how to recognise reputable sources and how to cite correctly. Their communication develops as students explain concepts, assumptions, and calculations to teammates on the interdisciplinary portion of The Challenges in order to make collective design decisions. This builds precision in language, logical structuring of arguments, and the habit of making implicit reasoning explicit. Closely related to this is collaborative communication within teams, where students learn to ask productive questions, listen actively, negotiate meaning across disciplinary boundaries, and use shared artefacts such as sketches, models, and design documents to align understanding, so communication becomes a tool for coordination and joint problem solving rather than simple information transfer.

Another facet is audience-aware communication, which is cultivated because projects require students to present their work to different stakeholders, such as tutors, peers, and non-specialist audiences. D&PS1 lectures focus on ways to translate complex technical content into accessible explanations without losing essential meaning, to frame problems in terms of user needs and constraints, and to adapt tone, depth, timing and terminology to suit the audience (Bains, 2019). Students then use these principles to put together a 5-minute presentation on an emerging technology in their context which they then present to peers across the faculty.

Visual and multimodal communication is another important facet embedded in PBL on the programme. Students are taught how to represent data through various visualisation techniques and are taken through ways in which data representation can be manipulated to lead the reader on e.g., truncation of the y-axis and scale distortion.

Students are then tasked with creating a visual that communicates data accurately, with an appropriate figure legend as briefly describing what the data shows and ways in which it can be misinterpreted.

Authentic assessment is also embedded via PBL by aligning what students are assessed on with what engineers actually do: framing problems, developing and justifying designs, communicating with stakeholders and reflecting on professional practice. Rather than relying primarily on unseen exams, assessment is built around project artefacts and performances that emerge from real engineering activity, aligning with authentic assessment principles (Vlachopoulos & Makri, 2024).

On the Engineering Challenges, students are assessed on a team design project on vaccine production for the treatment of tuberculosis in Uganda. This open-ended brief has marks attached to the quality of the proposed solution, the evidence used to justify design decisions, and how well the team engages with user needs and constraints. This mirrors professional practice, where engineers must propose defensible solutions rather than reproduce known answers. Assessment includes design reports and presentations in which students explain their design process, documenting iterations and failures, and justifying trade-offs, developing the ability to evidence decision making in a professional manner. Scenario weeks use intensive, time-bounded design challenges assessed through interim reviews, prototypes, and final presentations, which simulate real project milestones such as design reviews and client briefings. In later years, IEP projects and capstone-style work require students to produce integrated portfolios combining technical analysis, design rationale, testing evidence, and stakeholder-facing communication, often assessed through demonstrations and viva-style discussions.

Across these assessments, authenticity is reinforced because students are judged on process as well as product, on how they respond to constraints and uncertainty, and on how effectively they communicate technical work to different audiences. This means assessment becomes part of the learning process itself, with feedback on real project outputs shaping how students develop professional engineering judgement over time.

Example 7. How these competencies are embedded in the Biomedical Engineering scenarios

Teamwork is embedded through how the scenarios are structured. Biomedical engineering problems are deliberately complex and clinically framed (e.g., designing a wearable ECG monitor, a rehabilitation device, or an imaging workflow). Each scenario requires multiple engineering perspectives — electronics for sensing, mechanics for device design, and biomedical science for physiological relevance — so no single student can solve the problem alone. Teams allocate roles (systems integration, experimental design, modelling, documentation), manage interdependencies, and coordinate iterative prototyping and testing. The open-ended nature of scenarios forces teams to negotiate assumptions, handle

uncertainty, and resolve technical disagreements, mirroring multidisciplinary collaboration in healthcare engineering.

Communication is embedded through authentic biomedical engineering outputs. Students must communicate technical decisions: writing design reports that reference biomedical standards and safety constraints; presenting design reviews to academic "stakeholders" simulating clinicians or industry partners; and producing posters or pitches that translate engineering trade-offs into clinical value (e.g., patient comfort, data reliability, usability). Teams also document experimental validation (such as sensor calibration on physiological signals), requiring clear data visualisation and justification of methods.

Assessment and feedback reinforce both competencies. Group grades, peer assessment, and summative reflective components make teamwork behaviours visible and accountable. An example of questions used in the reflection is:

- Describe something non-technical that you learned this week. How is it helpful to you as an Engineer?*
- What have you learned about your strengths and your areas in need of improvement?*
- How would you describe your role within the team? What tasks were you involved with?*
- In terms of team dynamics, what would you say went well in this scenario? What didn't?*
- What are you going to do differently in the next scenario and what are you going to do again?*

Regular formative feedback on presentations and reports helps students refine how they explain complex biomedical concepts to mixed technical–clinical audiences. Over successive IEP scenarios, expectations scale up, progressively strengthening collaborative practice and professional communication.

5 Considerations for large-scale implementation of interdisciplinary PBL education

Whilst implementing interdisciplinary PBL at scale to develop competencies and skills offers significant learning gains, it brings notable operational and pedagogical challenges. Here we outline key considerations, intended as guidance for practitioners, and describe how they were addressed in our context.

Space, facilities and timetabling present an immediate pressure point. Large cohorts require flexible, reconfigurable spaces that support teamwork, prototyping and, where appropriate, hybrid delivery. Traditional lecture theatres constrain interaction and limit staff access to teams. Although securing suitable spaces is challenging, we have mitigated this through strong, multi-level relationships with the central space-allocation team, involving administrative staff, teaching teams and senior leadership. Recognising that not all institutions have access to UCL's facilities, we recommend flexible and efficient approaches, such as structuring sessions to combine independent

teamwork with targeted staff consultations, thereby reducing space demand while maintaining student support.

Assessing teamwork at scale is another challenge. Large cohorts, multiple assessors and interdisciplinary teams raise consistency concerns. Within the Engineering Challenges, a shared assessment rubric aligned to a common design cycle framework (Fig. 4.6.2) is used across departments. This has enabled consistent mapping of assessment outputs while accommodating disciplinary requirements. Prior work (Garcia-Souto et al., 2024; 2025) details challenges encountered and solutions implemented to preserve authentic interdisciplinary teamwork while ensuring discipline-specific learning outcomes for accreditation.

Uneven student contribution further complicates teamwork assessment. To address this, reflective components and the IPAC methodology were embedded, supporting accountability, team dynamics and assessment validity while reducing staff intervention (Garcia-Souto, 2024). The IPAC system is now integral to IEP modules and widely adopted across UCL Engineering and beyond (University College London, n.d.).

Finally, successful PBL implementation required a shift in staff skills and mindsets. Capacity building followed two strands: reinforcing IEP culture through senior leadership support and recognition and providing structured professional development. This included university-wide programmes for new lecturers, bespoke workshops on active learning and assessment, individualised support, and collaborative curriculum redesign focused on programmatic skills mapping (Perovic & Young, 2025). Dedicated training for Teaching Assistants ensured consistent delivery and feedback, while leadership opportunities supported TA professional development.

6 Concluding remarks

Engineering education is evolving in response to global challenges, technological change, and industry demands by embedding transferable skills such as communication, teamwork, ethical reasoning, and systems thinking alongside technical knowledge. Frameworks including AHEP4 and UNESCO's sustainability competencies emphasise the importance of these abilities for employability and innovation. At UCL, the IEP exemplifies this shift through PBL, interdisciplinary projects, and authentic engineering challenges that embed skills development from the first term.

The Biomedical Engineering programme at UCL demonstrates how this framework can successfully balance technical content with professional competencies. Developed alongside the IEP, the programme was able to integrate skills directly into technical modules rather than treating them as separate elements. Similar reforms were also achieved across existing engineering programmes, although these often-required significant restructuring and difficult decisions regarding curriculum content. Central to the programme's success has been a dedicated academic team maintaining a programme-level perspective, ensuring alignment across modules, coordinated assessment design, and progressive skills development. This has helped provide

students with a more rounded educational experience while avoiding unnecessary repetition.

Students increasingly recognise the value of these approaches, reporting improved confidence, independence, and preparedness for employment, findings supported by previous research such as Nweke (2021). Positive feedback from industry and accrediting bodies, including two successful IET accreditations, further highlights the effectiveness of embedding competencies and skills within engineering curricula. The experience also demonstrates how a small but focused engineering education team can drive broader institutional change and encourage colleagues to engage with innovative teaching practices.

Looking ahead, engineering education must continue adapting to the rapid rise of generative artificial intelligence. AI is already influencing student writing and approaches to learning, often improving presentation while sometimes leading to superficial technical understanding. Although generative AI offers valuable opportunities to support learning and future professional practice, overreliance and misunderstanding of its limitations remain concerns. In response, the IEP aims to teach students how to use AI critically, ethically, and effectively, while future plans include integrating AI into assessments to evaluate both AI literacy and understanding of its limitations. Ultimately, engineering programmes must remain flexible and forward-looking to prepare graduates for the changing demands of the profession.

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AI statement

During the preparation of this work, the authors used Microsoft Copilot in order to check grammar and spelling, standardise the use of British English and tense-check. After using this tool, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

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Multi-Level Integration: Transferable Skill Development at the University of Birmingham

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The University of Birmingham School of Engineering (United Kingdom) employs a multi-level approach to foster students' transferable competencies and skills. This integrated strategy, underpinned by conceptualisations of professional identity and engineering student belonging, operates across institutional, faculty, and curriculum levels. At the institutional level, the Birmingham Graduate Attributes cultivate skills through the qualities of intellectual curiosity, future focused, and practical wisdom. Concurrently, the co-curricular Birmingham Engineer Professional Identity Framework develops skills through professional identity via engineering perspectives such as professional registration and engineering habits. Finally, in the curriculum, Integrated Design Projects develop skills through interdisciplinary challenge-based learning in group settings. This holistic framework ensures that, during their studies, learners develop robust transferable competencies and skills for their future careers, enabling them to make broader societal contributions in line with the university's civic commitment to be at the centre of its region's renaissance.

1 Introduction

1.1 Context and rationale

The University of Birmingham is a research intensive, internationally reputable public university located in the West Midlands in central England, considered the heart of industrial Britain. It has been consistently placed in the top 100 world universities (University of Birmingham, 2025). Its engineering education programmes exist within the context of a large multidisciplinary Engineering faculty of ca. 2500 students and ca. 150 academic staff.

At the start of the twenty-first century the landscape of UK higher education shifted significantly, with increasing marketisation creating an imperative to prioritise student satisfaction and employability. In this context, where students are perceived as customers, a robust and flexible transferable skills development framework was needed to deliver improved student experience. Furthermore, this had to be flexible enough to support a diverse student cohort from several engineering disciplines, who are equally split between home and international students. The merger of Civil, Electrical, Electronic & Systems, and Mechanical Engineering schools in 2015 served as the catalyst for this change, presenting a unique challenge to unify transferable skill development.

1.2 The University of Birmingham's multi-level skill framework

Our multi-level skill framework is designed to be synergistic to ensure that skills are developed, contextualised, and recognised across the entirety of the student experience, in and outside of the curriculum. The framework operates at three distinct levels, each conceptualising skills through a distinct lens so that abstract graduate qualities are grounded in engineering:

- *Institutional level.* The Birmingham Award and My Attributes Platform. This university-wide initiative establishes the core principles for skill development and reflection through the lens of qualities: the Birmingham Graduate Attributes (see Sections 2.2 and 4.1).
- *Faculty level.* The Birmingham Engineer, a professional identity framework that acts as a crucial bridge by contextualising the Birmingham Graduate Attributes through the lens of professional identity, thus supporting the development of a sense of belonging (see sections 2.3 and 4.2).
- *Curriculum level.* Integrated Design Projects (IDPs) put theory into practice, conceptualising skills through the lens of competencies, so that students can demonstrate they can apply those skills in a professional context. The IDPs are a series of challenge-based, multidisciplinary level 6 modules — in accordance with the European Qualifications Framework (EQF) — run across multiple engineering programme. They serve as the primary setting where students learn a range of transferable skills in a scaffolded, team-based environment (see sections 2.3 and 4.3).

1.3 Chapter overview

This chapter presents a holistic, multi-level framework for transferable skill development, offered as an evidence-based case study and actionable guide for institutions seeking to implement a similar approach. We move beyond single interventions by connecting institutional graduate attributes to faculty professional identity formation and challenge-based learning. Section 2 describes our underlying philosophy and models. Section 3 describes the change management required. Section 4 presents case studies of each level in practice and the student journey. Section 5 concludes with a summary, outlook, and advice for practitioners.

2 Conceptual foundations: understanding transferable competency and skill development at Birmingham

Table 4.7.1 provides a high-level overview of our framework, listing the key aspects and activities at each level, and the lens through which skills are conceptualised and presented to students.

Table 4.7.1: The University of Birmingham's multi-level skills framework.

<i>Birmingham initiative</i>	<i>Level</i>	<i>Lens</i>	<i>Key aspects/activities</i>
The Birmingham Attributes and Award	Institution	Qualities	Intellectual curiosity, future-focused, practical wisdom
The Birmingham Engineer Professional Identity Framework	Faculty	Identity	Professional registration, engineering habits of mind
Integrated Design Projects	Curriculum	Competencies	Multidisciplinary, challenge-based teamwork

2.1 Theoretical underpinnings and application framing

The approach to transferable skills development at Birmingham draws on educational psychology and pedagogical theory, particularly Vygotsky's (1978) concept of zone of proximal or potential development (ZPD) — the gap between what the learner can do independently and what they can achieve with guidance of educators and/or more knowledgeable peers. The related idea of scaffolding (Wood et al., 1976) describes the temporary structures that enable learners to function within their ZPD and then move beyond it. Both theories emphasise the social nature of learning, highlighting the importance of interaction, language, and cultural context in developing analytical and practical skills, including in STEM education (Rahman, 2024).

Bloom's revised taxonomy (Anderson & Krathwohl, 2001) adds a cognitive structure to this social framing, supporting the use of formative feedback, peer mentoring, and problem- and design-based learning as methods to promote progression. These strategies guide learners through iterative challenges that shape their personal and

professional identity. Integrated Design Projects (Section 4.3) make direct use of ZPD and scaffolding principles. While educators often apply ZPD intuitively, explicit application has stronger and longer-lasting effects, benefiting students and the professional community.

The Birmingham Graduate Attributes (Sections 2.2 and 4.1) and related initiatives that strengthen learners' academic and disciplinary belonging also connect to these frameworks, highlighting the value of guided interaction, structured support, and aspirational thinking in shaping learning outcomes within the Birmingham engineering community.

A sense of belonging (Section 2.3) fostered through psychological safety as explored by Edmondson et al. (2016), then acts as a catalyst for deeper engagement, sustained motivation, and self-efficacy (Lytle & Shin, 2020). When students feel recognised and valued, they are more likely to take intellectual risks, seek feedback, and collaborate meaningfully. This emotional and social anchoring complements the cognitive and pedagogical structures above, reinforcing the impact of scaffolding and ZPD-based approaches in shaping confident, capable graduates, and links these practices to the Birmingham Graduate Attributes that frame how skills, qualities, and values are cultivated across the university.

2.2 The Birmingham Graduate Attributes

These institution-wide attributes were first launched in 2015 and were intended to help drive and contextualise all faculty-level skills initiatives, including those in Engineering. Education leaders were tasked to ensure that all students experienced a range of carefully crafted activities to help them to develop attributes deemed to be essential qualities that will help learners to be successful in their study, work, and wider lives. Following a three-year process of research, consultation, and revision, the attributes were revised in 2023. In this current formulation, nine attributes sit under three overarching headings.

1. *Intellectually curious*: to be self-motivated researchers and learners, engaging in cutting-edge academic disciplines.
 - a. *Subject specialists*: experts in discipline-specific knowledge and enquiry-informed practices.
 - b. *Critical and creative thinkers*: analytical and independent reflective thinkers.
 - c. *Interdisciplinary as people*: possessing a breadth of knowledge beyond specialist subject that is shared with others.
2. *Future-focused*: to be resilient and innovative in the activation of positive change with a commitment to lifelong learning and personal development.
 - a. *Instinctively digital*: ability to use and evaluate new and emerging digital technologies.
 - b. *Entrepreneurial spirit*: creative with the ability to generate ideas and lead change that benefits others.
 - c. *Sustainability-focused*: committed to sustainable development in every aspect of life.

3. *Practical wisdom*: to act with humility, confidence, and good judgement to do the right thing at the right time.
 - a. *Socially engaged*: actively helps others and the wider community to flourish.
 - b. *Natural collaborators*: works collaboratively and can communicate with diverse audiences. Removes barriers for people who are different from themselves.
 - c. *Courageous integrity*: takes on new challenges. Committed to truth and acts in alignment with moral principles.

While no list of attributes can be definitive, in developing this current list, it was important to ensure there was a balance between the skills, qualities, and values that will help students become successful in their life or career, as well as those that are necessary for them to contribute positively to their communities, in line with the university's broader civic mission. Through widely championing a list of nine attributes, the aim is for academic and professional services colleagues to adapt them into the context of their work, in ways which best support learners to develop the essential knowledge, skills, and character qualities required to flourish in the modern world.

The transferable competencies and skills as distinguished in this handbook can be associated to the nine attributes, with the caveat that any association may be up for debate. For example, both Birmingham Graduate Attributes 'subject specialists' and 'instinctively digital' fundamentally rely on the ability to 'seek, evaluate, use, and create information effectively', that is, information literacy. A suggested mapping comparing the nine attributes against the competencies and skills as formulated in this handbook is provided in Table 4.7.2. This will assist readers in formulating their own attributes or considering their existing institution's graduate attributes, where available, and relating them to transferable competencies and skills.

2.3 Operationalising skills and the role of student belonging

Student belonging, defined as "*a feeling or sensation of connectedness, and the experience of mattering or feeling cared about, accepted, respected, valued by, and important to the campus community or others on campus such as faculty, staff, and peers*" (Strayhorn, 2018, p. 4), is a relational and developmental quality of the student experience. It interacts with students' expressed and perceived identities as they move through their academic and professional journey.

Belonging is more than 'fitting in': it is a set of skills that enable individuals and groups to interact safely and meaningfully, build knowledge, and create meaning together. Belonging connects closely to personal qualities such as resilience, engagement, and courage.

It makes proactive engagement easier, while also acting as a buffer against adversity. Structural and societal barriers to belonging in engineering must therefore be recognised, especially for minoritised and marginalised groups, alongside situational challenges such as module or group dynamics. Addressing these barriers requires both supportive learning environments and broader institutional action. Offering alternative and culturally diverse perspectives on engineering problems accelerates authentic

development, while curriculum decolonisation broadens the range of approaches available to students. This is not about substitution but expansion, enhancing adaptability, cultural awareness, and 'courageous integrity'.

Table 4.7.2 Mapping of Birmingham Graduate Attributes to this handbook

	<i>I - Responsibility, project management, and leadership</i>	<i>II - Communication and interpersonal skills</i>	<i>III - Professional commitment/ lifelong learning competencies</i>
<i>1.a Subject specialists</i>	Project management (on process level)	Written reporting skills	Information literacy skills
<i>1.b Critical and creative thinkers</i>	Risk analysis and risk management skills	Listening skills	Self-reflection
<i>1.c Interdisciplinary</i>	Project management (on process level)	Teamwork; multi-, inter-, and transdisciplinary teamwork	Learning strategies
<i>2.a Instinctively digital</i>	Operational awareness	Visualisation skills	Information literacy skills
<i>2.b Entrepreneurial spirit</i>	Leadership skills	Pitching skills	Initiative
<i>2.c Sustainability focused</i>	Risk analysis and risk management skills	Adaptive communication style	Adaptability for change
<i>3.a Socially engaged</i>	Leadership skills	Interconnection/ interrelation ability	Autonomous motivation
<i>3.b Natural collaborators</i>	Meeting skills	Teamwork; collaborative goal setting	Self-regulation
<i>3.c Courageous integrity</i>	Leadership skills	Giving feedback	Resilience

A recently developed engineering student belonging model (Cooke et al., 2023) combines psychologically safe, culturally diverse teamwork, professional identity, curriculum decolonisation, and race equality promotion as complementary elements (Fig. 4.7.1).

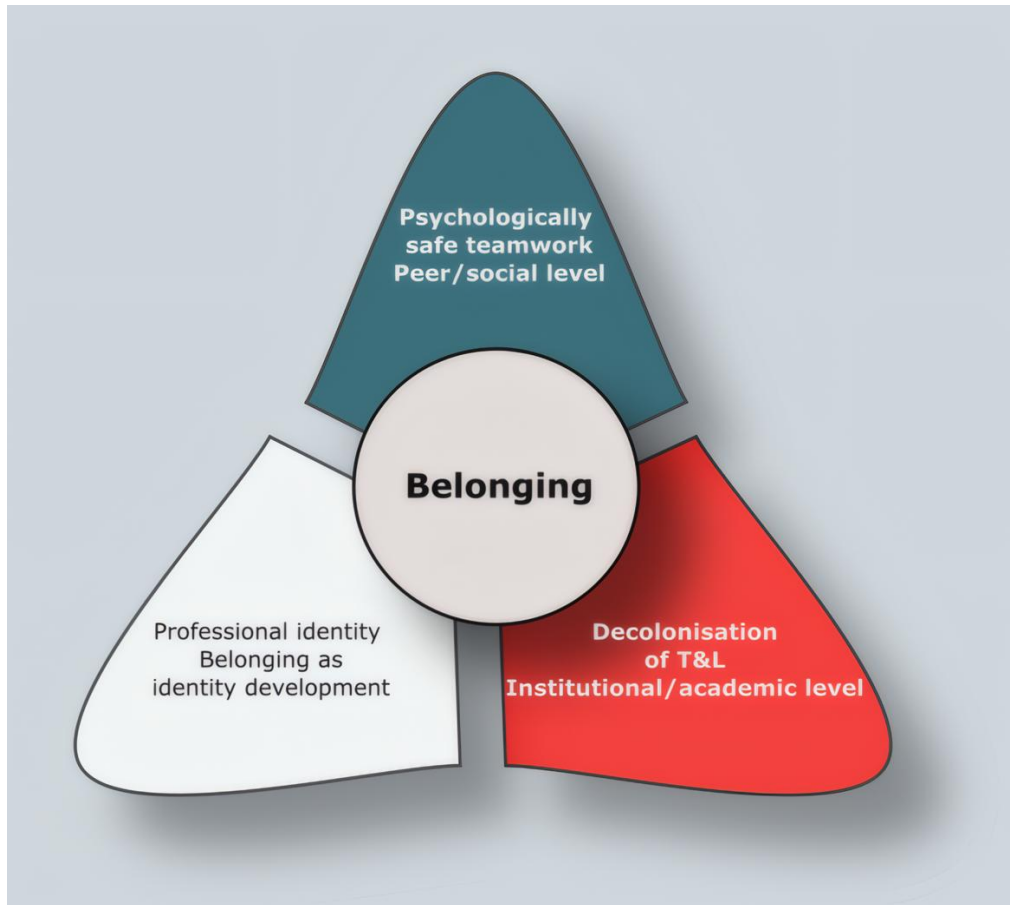


Figure 4.7.1: Engineering student belonging model, artwork by Favero (Own Work)

The principles of this model shape the practical design of transferable skills at Birmingham. For example, the Integrated Design Projects (Table 4.7.1, Section 2) are structured to promote psychologically safe and culturally diverse teamwork in scaffolded settings. Likewise, the Birmingham Engineer Framework (Table 4.7.1) supports the development of students' academic self-concept as emerging professionals.

In this way, belonging is embedded in the multi-level skills framework: institutionally through initiatives such as the Birmingham Award and My Attributes Platform, co-curricular through the Birmingham Engineer, and in the curriculum through IDPs. This alignment creates a synergy between personal identity, peer interaction and institutional culture, ensuring that belonging functions both as a developmental experience and as a transferable competence across all levels of the framework. These dimensions also connect with the three levels of the belonging model that follow: individual, peer, and institutional.

Individual level: belonging as identity development

On an individual level, student belonging is closely linked to identity development as learners and future engineers (Lytle & Shin, 2020). As demonstrated by investigations of belonging at the individual student level (Dost, 2024; Dost & Mazzoli Smith, 2023), initiatives that address both identity and belonging together promote growth while reducing isolation and alienation. The development of belonging in the students as a process at Birmingham is supported through skills-focused programmes such as the Birmingham Engineer, which frames identity as social, personal, and domain-specific.

Peer/social level: teamwork and interaction

Peer interactions play a central role in shaping how students engage with others, navigate team dynamics, and develop a sense of belonging within the wider engineering learning community. Teamwork offers opportunities but also challenges, especially in culturally diverse context where norms may be unfamiliar. Ongoing research at Birmingham shows that learners from diverse social or cultural backgrounds, including international students, can feel unsettled by dominant cultural norms. In response, educators have introduced smaller group sizes, structured heterogeneity, role definitions, and communication training (e.g., leading meetings, productively engaging with peers, and managing conflict). These interventions build confidence and belonging while developing skills aligned with both the Birmingham Graduate Attributes and the Birmingham Engineer.

The emphasis on psychologically safe teamwork is reinforced by principles of non-violent communication (Pinto et al., 2023) and by recognising cultural and personality differences. Rather than assuming prior knowledge, educators actively support students in developing respectful, inclusive collaboration skills. This reduces reliance on staff to manage conflict and encourages autonomous, constructive teamwork, ultimately enhancing students' sense of belonging and their ability to co-create knowledge.

Institutional level: inclusive culture

At the institutional level, belonging depends on policies, practices, and cultural frameworks that shape the learning experience. Students must not only access disciplinary knowledge but also feel empowered to influence institutional culture. This requires developing contextual competencies: understanding and navigating academic and professional norms while contributing to them.

At Birmingham, inclusion is a strategic priority, reflected, among others, in race equality initiatives, curriculum decolonisation, and inclusive pedagogy. These broaden perspectives and problem-solving approaches students are exposed to and enhance adaptability, cultural awareness, and what Birmingham terms 'courageous integrity' as defined in the Birmingham Graduate Attributes (Section 2.2). Curriculum decolonisation is framed as constructive — broadening rather than replacing — and is tied to students' academic self-concept and professional identity as individuals and as part of a community of knowledge.

Institutional belonging also means tackling systemic barriers faced by minoritised and marginalised groups, not just individual or situational challenges. Practices that create inclusive environments help students feel recognised, supported, and able to thrive. In turn, this reinforces belonging as relational and developmental, deeply embedded in the social and institutional fabric of engineering education.

3 Catalyst: The School of Engineering merger

Our multi-level skills framework was an organic response to the top-down 2015 merger of engineering schools to create a new School of Engineering. This section details key aspects of the change process: its catalyst, the challenges it presented, and how they relate to the skills framework that was developed in response, driven by faculty engagement and buy-in to the change.

3.1 The catalyst: a school-wide merger

The School of Engineering is a combination of three departments: Civil Engineering, Electronic, Electrical & Systems Engineering and Mechanical Engineering. It was formed in 2015 due to market, economic, and organisational imperatives, as well as the complexity and demands of a modern engineer. Such an amalgamation required strong leadership, coordination, and detailed planning to ensure a smooth transition. The complex nature of the merger led to a number of challenges, including change in the environment, estate, relocation, and emotional attachment to previous schools and their cultures. In breaking down disciplinary silos, it provided a unique opportunity to unify transferable skill teaching across engineering disciplines.

3.2 Addressing the merger's key challenges

Integrating diverse student cohorts

We implemented a revised structure for the delivery of the undergraduate curriculum, including a shared common first year for all disciplines. As part of the process to support the integration of this diverse student cohort, the skills framework was instigated. The Birmingham Engineer (Section 4.2) was rolled out across all programmes, supported by personal academic tutors. In tandem we developed the Integrated Design Projects (Section 4.3), a flagship suite of modules running from the first to third years of the three- and four-year bachelor degree programmes. Furthermore, visiting professors from industry were appointed to support the development of an industry-ready curriculum. Careful consideration was given to all school aspects, including education support and administration, student well-being, integration, and culture.

Scaling the student experience

To meet the challenge to maintain a personalised, inclusive student experience in response to increased student numbers, we responded with strategies to improve perceptions of belonging (Section 2.3) including professional identity through the Birmingham Engineer. The demand to enrol on Engineering degrees in the UK has risen over the past decade (Fowler et al., 2023). Indeed, cohort sizes at Birmingham increased significantly since 2020, with undergraduate and postgraduate total

populations growing approximately 25% to 2500 in 2025. This dramatic rise in student numbers risked a depersonalised and diluted student experience; therefore, a scalable support strategy within institutional constraints was fundamental. As is often the case, the increase in cohort size did not lead to an immediate in-step increase in resources of the same proportion. Notably, maintaining practical skills within the curriculum, such as laboratory and workshop practical skills, was the key challenge, compounded by the greater emphasis on teaching transferable skills. This challenge was met by encouraging co-curricular activities, including a state-of-art makerspace for students to pursue personal interest projects as part of the Birmingham Engineer.

Navigating accreditation demands and entry patterns

The majority of our degree programmes are accredited by the relevant professional engineering institution (PEI) through the UK Engineering Council framework (Accreditation of Higher Education Programmes (AHEP) (Engineering Council, 2021). We learned several lessons. Notably, the interpretation of AHEP for each PEI varied, guided by subject-specific learning outcomes. Consequently, requirements on their assessment had to be satisfied in programme designs in such a way that no discipline fell short of its accreditation requirements. Early identification of issues was fundamental to this process. Moreover, updated versions of AHEP, notably AHEP4, required reconsideration. Notably with reference to Bloom's taxonomy (Anderson, 2021), the cognitive level for many of the learning outcome areas was raised, changing requirements from understanding and applying to creating and evaluating. Moreover, not all students arrive at the beginning the first year (IET, 2021). Other entry patterns include foundation year and direct entry into Years 2 and 3 from regional colleges and international partner universities, as well as Degree Apprentices from industry partners, which include mature students. The coherent structure of our multilevel skills framework to cater to all engineering disciplines in a unified presentation fulfilled these needs to deal with multiple accreditation bodies and student entry patterns.

Education-focussed career pathways for academics

Finally, we recognised that the challenge of developing a skill framework within a multidisciplinary engineering context amidst the pressures of a research-intensive institution could not be solely met by an academic body primarily motivated and incentivised through maximising grant capture and scientific publication. An education-focussed path was offered to academics to ensure faculty capacity could expand to meet this challenge of developing the new education offer and student experience. This freeing up of academics' time from research to focus on education value-creation included developing the skills framework. Over time this has had the result of facilitating the development of engineering education research and scholarship within the academic body. Valid concerns about career stagnation by academics in education-focussed routes were met by the school's leadership moving on to create a comprehensive and transparent promotion system across the whole university in December 2021 – The Birmingham Academic Career Framework (Sterling et al., 2023). This provided 3 core promotion pathways for staff to follow: Research

and Education, Education, and Enterprise, Engagement and Impact. This has subsequently created several professors in engineering education.

Adaptation and resilience: aligning with institutional strategy

In 2021, the university launched its Birmingham 2030 strategic plan. It set out a visionary framework for the institution, focusing on sustainability, innovation, and inclusivity. It introduced a fresh institutional language emphasising collaborative growth, interdisciplinary research, and community engagement (University of Birmingham, 2021). Because our skills framework preceded the plan, we had to retrofit it to align with this new context. This alignment process was significant: the graduate attributes (Section 2.1) were updated from their 2015 version, the Birmingham Engineer was revised with more action-oriented language to encourage more students to participate in skill-development activities, and the IDPs incorporated a stronger focus on transferable skill reflection. Our successful adaption validated our approach, proving it to be robust to university-level strategic shifts while maintaining integrity and relevance to engineering in meeting the needs of students, accrediting bodies, and industry.

4 The multi-level initiatives in practice

Having established the theoretical foundations in Section 2 — the ‘what’ — and the context for change in Section 3 — the ‘where’, ‘why’, and ‘when’ — this section details the practical application of the framework — the ‘how’. We describe each of the three levels separately, finishing with an example of a student journey to illustrate the interplay between levels to create a single, cohesive experience.

4.1 Institutional-level initiative: the Birmingham Graduate Attributes, Birmingham Award and My Attributes platform

While the Birmingham Attributes described in Section 2.2 are ‘caught’ through the ethos, values, and culture of the organisation, they are also more explicitly ‘taught’. Students are offered planned opportunities to develop the attributes. Examples of opportunities afforded to all students include ‘My Attributes’, a digital portfolio developed by the University Careers Service, and the opportunity to receive the ‘Birmingham Award’.

My Attributes platform

The My Attributes platform is optionally available to all students to review, and aims to reward them for developing knowledge, skills, and attributes necessary for study, work, and life. We developed this in consultation with students. On the platform, students can access the assessment section to self-audit their skills and attributes and gain a personal overview of the strengths and competences they might seek to develop further. Students also have access to learning pathways for each of the graduate attributes. The primarily online learning modules enable students to develop their knowledge and understanding about the graduate attributes through the completion of self-directed learning activities. Learning activities are available for them to work through at their own pace.

The Birmingham Award

The Birmingham Award is an optional programme that undergraduate students take alongside their degree to develop, recognise, and articulate the attributes they have developed from engagement in student life at Birmingham. Students can choose from a portfolio of circa 250 activities that are part of student life, each mapped to the graduate attributes. If students complete four attribute reflections on extracurricular activities which they feel have helped them to develop one or more of the graduate attributes, they will be rewarded by gaining the Birmingham Award on their graduation transcript. Students who complete it are offered the opportunity to gain the more advanced Birmingham Award with Distinction. The Distinction level is a quality-assured structured education programme that allows a learner to explore and develop a deeper understanding of their attributes through online and classroom-based teaching sessions, co-produced with graduate recruiters. Every year c. 2000 students enrol onto the award, from a range of undergraduate year groups and disciplines. The most recent post-evaluation self-assessment indicates that of the students who completed this optional programme in 2022-23, 87% were motivated to undertake further action to enhance their employability as a direct result of undertaking the award. Individual student reflections also show that the Award has helped them to develop their attributes gained and to articulate them, particularly within an employability context.

4.2 Faculty-level initiative: the Birmingham Engineer Professional Identity Framework

Bridging the gap between institution and profession

While the attributes set a general transferable skill development, the faculty needed to relate it to engineering. As a vocational subject, skill requirement is specified through PEIs for accreditation and employer needs. To bridge this gap in institutional expectations of graduate attributes to that of PEIs, we developed the Birmingham Engineer Professional Identity Framework.

Engineering identity

Defining engineering identity and its progression has gained interest over the last decade. Many identity studies in STEM education define it according to the conceptual model by Carlone and Johnson (2007), which comprises three overlapping aspects of identity: social, personal, and domain (engineering). The Birmingham Engineer builds on this model (Fig. 4.7.2). The Engineer aspect of student identity (left plane, more detailed in the middle plane) is developed by cultivating the student's subject interest, recognition, ability and performance. The embedding framework (right plane) comprises of four dimensions:

1. *Accreditation*. the learning outcomes of an accredited degree as defined by AHEP4 (Engineering Council, 2021).
2. *Institutional*. general skills and competences desired by the university for all students as defined by the Birmingham graduate attributes.
3. *Habits of mind*. thinking patterns associated with engineering professionals as defined by the Royal Academy of Engineering (Lucas et al., 2016).

4. *Career.* consideration of future identity and career.

Each dimension has an inventory of relevant skills and career aspirations associated with it, which is updated yearly in line with new approaches and policies. The overview in Fig. 4.7.2 is an example of a complete inventory.

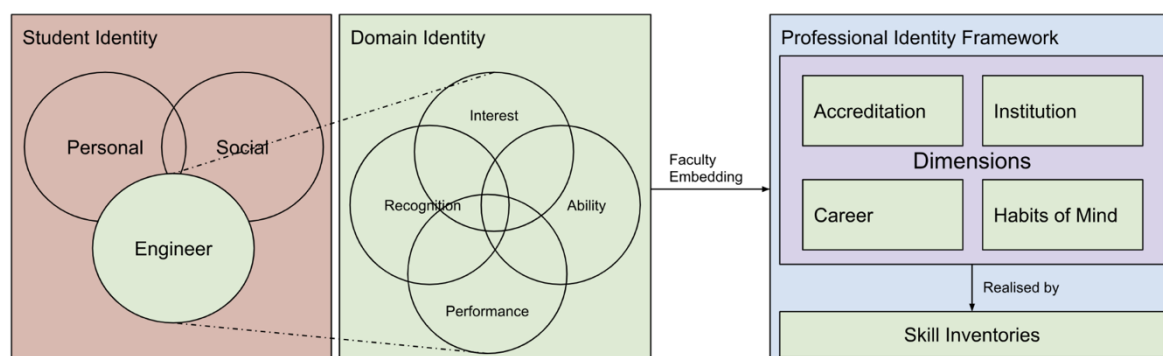


Figure 4.7.2: Professional identity embedding framework for engineering identity (Own Work by Cooke)

Process of activation and reflection

Students reflect on skill development through curricula and co-curricular experiences during their academic reviews. These are meetings held three times a year with their tutors — an academic assigned to them throughout their study to monitor their progress, provide academic support, and assist in referral for pastoral issues when necessary. To prepare for these meetings, against each skill specified in the skill inventories for the Birmingham Engineer, students rate themselves on a five-point Likert scale and upload one piece of work they have done as evidence.

Crucially, this process is not only reflective but also activates students' development of skills. For example, to acquire engineering habits in dimension C, students are encouraged to begin a passion project outside of the curriculum such as designing or building something in the school's makerspace — a state-of-art facility supporting both additive (3D printing) and subtractive (machining) manufacturing processes, visualisation tools (virtual reality), and electronics-printed circuit design. Likewise, attending industry-run events is seen to progress dimension D.

Useful analytics

Insightful analytics are available from the reflections students provide for their tutor meetings. We have used text analysis tools to examine word frequencies in students' written reflections of their skills to help reformulate our choice of words when describing the Birmingham Engineer's dimensions (Cooke, 2020). In the academic year 2024/25, students showed a small yet significant increase in identifying as an engineer — the average score increased from 3.9 in Year 1 to 4.2 in Year 3 (n=1178). Beyond tracking identity over time, the data allows for a deeper analysis of how students perceive the relationship between different skills and career motivations. To

explore this, we analysed the skill ratings from our 2020/21 cohort using a statistical technique called agglomerative clustering. This method groups skills into a hierarchy based on how closely each student's ratings correlate, in essence creating a dendrogram (family tree) of related skills and career preferences (Fig. 4.7.3). This analysis reveals a logical and insightful structure to the students' developing professional identity from students in Year 2 upwards. We observed two primary clusters:

1. a 'core engineering' cluster, comprising of skills like engineering design, analysis, creativity, and systems thinking.
2. a 'transferable skills' cluster, which included skills such as learner strategies, leadership, and communication skills.

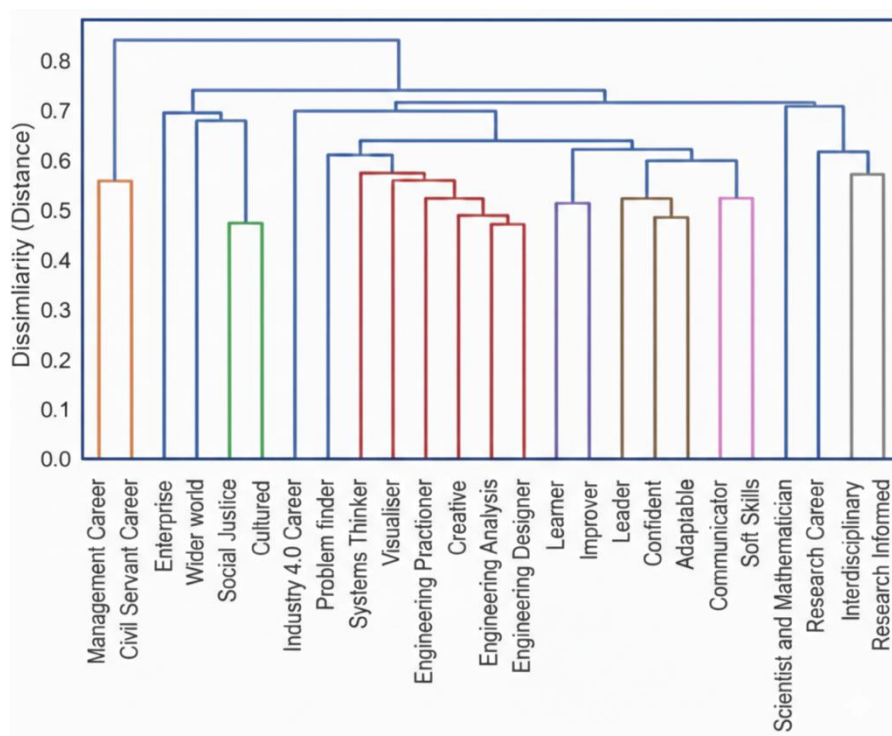


Figure 4.7.3: Dendrogram showing agglomerative clustering of self-ratings of skills by students in Year 2 upwards (n=263). The colours represent automatically identified clusters (Own Work by Cooke, 2021).

Crucially, these two clusters were strongly correlated with each other and with a stated motivation to pursue a career in industry. In contrast, a separate skill cluster including science and mathematics, interdisciplinary skills, and research-informed practice is correlated with a motivation to pursue a research career. This data-driven insight suggests that students appear to be forming coherent and distinct skill profiles that align with their career aspirations, providing evidence that the Birmingham Engineer is helping them to understand, develop, and articulate their unique identities. Notably,

the same analysis of first-year students reveals no comparable structure, suggesting a valuable progression.

4.3 Curriculum-level initiative: Integrated Design Projects (IDPs)

The IDPs support the students' development of transferable skills and competencies in each year up to the third year of level 6 study. They employ challenge-based learning in multidisciplinary teams to find environmentally, socially and economically sustainable engineering solutions to real word problems. Each IDP module is 20 credits of 120 total credits awarded per year towards a degree, which is equivalent to 10 credits in ECTS. Each develops a key transferable competence area which can be broadly described as foundational, collaborative, and leadership for Years 1, 2 and 3 respectively.

Year 1: developing foundational competencies

IDP1 for first-year students is split into two parts. In the first, students develop individual professional engineering skills necessary to build a solid foundation as an engineer. These include research skills, report writing skills, presentation skills and design skills. The design process includes concept design sketches, product design specification, and computer-aided creative designs. In the second part, students build on the CAD skills developed in semester 1 by completing a more advanced design project and are introduced to teamwork to start building their collaborative competencies. They also complete an industry-standard project management spreadsheet to provide them with foundation-level project management skills that will be built on as they progress through their programmes.

Year 2: developing collaborative competencies

In IDP2, students in their second year develop collaborative competencies by completing two main assignments. For assignment 1, they complete an interdisciplinary team project which develops teamwork and project management skills. The real-world challenge project is typically motivated around the United Nations SDGs (Cooke, 2018), for example a concept design for an indoor vertical farm in a smart city. There are six students per group. To support teamwork, the assignment briefs provide detailed guidelines. The students follow sessions introducing them to project management principles including non-violent communication (Pinto, 2023), how to work effectively in a team, life cycle analysis, and building a business case. At the end of assignment 1 students are asked to reflect on the transferable skills needed for effective teamwork. In assignment 2 students are reallocated to discipline-specific teams with a shift in emphasis from transferable skill development and systems thinking towards discipline-specific designs. Because assignment 2 necessitates new groups, students have the opportunity to improve their transferable skills by putting into practice their reflections on teamwork required in the first assignment. Consequently, the teamwork experience is generally better.

Year 3: developing leadership competencies

For IDP3, third-year students take on a less structured and scaffolded real-life contemporary engineering design challenge which enables a focus on developing leadership competences. Whilst previous IDPs are taken exclusively by undergraduate students, the IDP3 cohort also includes postgraduate students from the MSc Advanced Mechanical Engineering programme, further diversifying the student cohort. IDP3 takes an innovative and intricate approach to teamwork. Like IDP2, students are divided into cross-disciplinary teams. However, the team size is bigger, typically up to 40 students. It is further divided into discipline-specific project groups to work on activities to feed into the team solution. To support accreditation requirements, distinction is also made in assessment criteria between students in bachelor (EQF level 6) and master (EQF level 7) engineering degrees.

A practical example of how a team challenge is distributed amongst the discipline-specific groups is shown in Table 4.7.3. To ensure students get a full experience of real-world engineering, there are several assessments. These include analysing the ethics of their design and identifying any risks, including health and safety and cybersecurity. In addition to leadership, students develop business and entrepreneurial competencies requiring financial plans, with MEng students required to provide a full business plan incorporating a financial forecast for the product as well as producing a prototype of it, allowing them to further develop practical engineering skills in addition to the transferable and design skills.

Table 4.7.3 Examples of team challenges and associated group design projects.

<i>Team challenge</i>	<i>Civil</i>	<i>Electrical</i>	<i>Mechanical</i>
<i>Develop smart infrastructure systems</i>	Structural design, sustainable construction materials, novel applications for advanced materials	Smart grids, sensing and control hardware and software	Provision of sustainable energy and power for infrastructure, adaptive movable components
<i>Improve energy efficiency of the UK housing stock</i>	Zero net carbon houses, micro-wind turbines for houses	Smart meters and intelligent appliances	Heat and air management, insulation materials, phase change materials
<i>Transportable and/or adaptable health care systems for conflict zones</i>	Structure for deployment, training facility and sustainable construction materials	Communications or power support infrastructure and portable data processing	Diagnostic, trauma or treatment equipment that can be transported, deployed, and administered rapidly

4.4 The student journey: an integrated experience

In this section we present a composite student, Maria, a female electrical engineering student, showcasing how she experiences the framework to illustrate how the interplay between different levels produces a unified journey.

Institutional level: the My Attributes platform and Birmingham Award

Maria signed up to the My Attributes platform (Section 4.1) during her first year, becoming familiar with the nine graduate attributes and recognising that many activities are transferable skill development opportunities. As a keen rugby player with coaching responsibilities for the back line, which include conducting post-performance analyses using game video footage, she has identified 'socially engaged', 'natural collaboration' and 'instinctively digital' as strengths from her rugby experience. She logs this extracurricular activity as developing her future focus and practical wisdom. She adds to her my attributes reflection that in rugby, players have different strengths and play different positions, and that during the game continual communication ensures everyone has a shared awareness. In the second year studying IDP2, she quickly recognises her teammates' comparative inexperience in teamwork.

Faculty level: the Birmingham Engineer

Maria is developing her engineering identity through the Birmingham Engineer (Section 4.2). Her tutor encourages her to take actionable steps to progress her profession along the four dimensions, e.g., join the Institution of Engineering and Technology (IET) to gain professional registration, keep the My Attributes platform up to date, develop a personal interest project in the makerspace, for example around wearable devices to monitoring head concussion in rugby, and explore potential engineering careers through participation in events run by the School of Engineering Employability Network (SEEN) — a school-wide platform supporting career development through strong integration with industry partners, including placements, skills sessions, and careers events.

Curriculum level: the IDP

In class, Maria is taking the IDP2 module (Section 4.3). She is in a team of five other students who are collaborating to develop a concept design for an indoor vertical farm in a smart city. To encourage student belonging and psychologically safe teamwork, the group has been constituted so that at least half are female. While this does not guarantee belonging and safety, we consider it a positive contribution towards it. She has taken the module's short courses in multicultural teamwork and inclusive leadership. Furthermore, she is being taught non-violent communication skills to resolve group conflict and anxiety. She immediately recognises that her experiences in playing rugby are transferable to the IDP2 group setting, where communication establishes trust, and group profiling using team roles is analogous to playing in a position. Based on the quality of these and similar reflections spanning institutional, faculty, and curriculum level, Maria is on track to attain the Birmingham Award for her skill development upon graduation.

5 Review, outlook, and advice

The strengths of our multi-level integration of skill development are to simultaneously foster in students a strong professional identity as engineers, while also capitalising on the strong sense of belonging and esteem which arises from the University of Birmingham's reputation.

5.1 *Reflection on the current situation*

Considering skills development at multiple levels in an institution invariably results in different presentations and skill lists, which risk stakeholder fatigue and confusion. Engineering educators will naturally focus on the learning outcomes as required by PEIs to assure accreditation. In most universities, institution-wide graduate attributes are laudable, anodyne, and perhaps interchangeable. However, they risk being considered irrelevant, unless a coherent integration between attributes and skills learned in the program is enacted. We have found that the key to realising this coherence is to both explicitly define the lens through which skills are conceptualised at each level — qualities, identity, and competencies in our case — with appropriate activities and presentation to maintain a perception of relevance and usefulness. Furthermore, our framework's segmented architecture is adaptable to new or revised initiatives without unduly affecting other parts. Finally, our nine graduate attributes ought not to be considered mutually exclusive or complete; we encourage and support students to develop any skill, character quality, and attribute they deem necessary to meet their professional and personal aspirations.

5.2 *Outlook*

Our work to develop the framework is ongoing. At the time of publication, the institutional-level skills framework is optional to the student; only the faculty-level and curriculum-level skills frameworks are embedded. To make the institutional-level framework more universal, implanting of the institutional-level framework into the curriculum is currently underway through the Ad Alta Pathway. Furthermore, a new incentive at faculty level includes a Birmingham Engineer Award for launch in 2027 to recognise participation at faculty level to reward participation in co-curricular activities which develop engineering identity.

5.3 *Advice to other engineering educators*

For fellow educators seeking to implement a similar multi-level approach, we offer three key recommendations.

- At institutional level, you should focus on developing nuanced graduate attributes that represent the culture and ethos of your institution alluding to clusters of skills rather than a boilerplate, generic skills list.
- At faculty level, you should promote belonging by creating a dedicated framework for engineering identity formation, integrating it into personal tutoring, and using analytics to track its impact.
- At the curriculum level, you should design a clear progression model for collaborative skill building during challenge-based learning, making

psychologically safe teamwork an explicit learning outcome supported by targeted interventions.

Ultimately, the success of this approach lies not in any single initiative, but in the intentional synergy created between all three levels.

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AI statement

During the preparation of this work, the authors used Google Gemini and Microsoft Copilot to improve clarity and readability. Figure 4.7.3 was originally generated in Python, then enhanced using Google Gemini to improve its resolution and to add a vertical axis label. After using these tools, the authors reviewed, edited, and made the content their own. They take full responsibility for the content of the publication.

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University of Melbourne: A Programme-Wide Framework for Teaching, Practicing and Assessing Teamwork

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In this chapter we describe a framework for teaching, practicing, and assessing teamwork (TPAT) across a degree programme. Teamwork is crucial for engineering graduates, yet current curricula often lack a consistent, programme-wide approach to developing teamwork skills. Students are often expected to work in teams without sufficient explicit instruction. Additionally, degree programmes might lack design of scaffolding for and assessment of the incremental development of teamwork. Our framework, designed for The University of Melbourne's Infrastructure Engineering programme, addresses this by providing a systematic approach to support and assess attainment of teamwork competencies and skills throughout a student's degree journey. The framework was developed through a process, beginning with a review of key literature on teamwork in engineering education. From this literature review a common definition of teamwork was synthesised, comprising seven dimensions (adaptability, feedback, communication, coordination, collectivism, leadership, and empathy) and several associated behaviours. These were mapped across the degree programme to ensure structured skill progression. Feedback from module coordinators helped refine this mapping to align with the existing curriculum and teaching needs. Teaching and assessment activities were then identified and aligned with each behaviour to support academics looking to implement the framework. The TPAT framework provides educators with a clear guide for systematically embedding teamwork competencies and skills into their curricula and could be easily adapted to other engineering programmes.

1 Introduction

Teamwork skills are recognised as essential competencies for engineering graduates, critical not only for academic success but also for effective professional practice (Ercan & Khan, 2017). Despite this recognition, teamwork skills are frequently expected from students rather than explicitly taught, and assessment of teamwork is inferred instead of systematically assessed. This expectation often leads to inconsistent development of teamwork skills, creating challenges for both students and educators.

In the University of Melbourne's Infrastructure Engineering programme, academics regularly faced uncertainty regarding which specific teamwork skills they could expect from students and felt they had to assume students had little to no prior skills. This was because the existing curriculum lacked consistency in defining and developing teamwork skills, and in adequately assessing those skills, resulting in a fragmented student experience and uneven skill progression across the degree programme. Based on these issues, the programme educational leader identified a pressing need for a structured and coherent programme-based approach to teaching and assessing teamwork skills and reached out to the faculty teaching support unit for help.

To address these challenges, we implemented a programmatic approach to teaching and assessing teamwork across a whole degree programme. Our primary goal was to provide clear engineering-specific definitions of teamwork, ensure progressive skill development throughout a student's academic journey, and help academics to design effective teaching and assessment activities they could implement in their modules.

In this chapter, we first detail the multi-stage process of developing our teamwork framework, including synthesising a coherent list of effective teamwork behaviours comprised of seven key dimensions: adaptability, feedback, communication, coordination, collectivism, leadership, and empathy. Second, we describe how these dimensions were mapped across the degree programme and embedded into modules, as well as the ongoing challenges in implementing this framework. Third, we present case studies highlighting three different approaches to implementing the framework in a module. Finally, the chapter concludes with a SWOT analysis and user guide.

1.1 University of Melbourne context

The University of Melbourne is a research-intensive institution with over 50,000 students across nine faculties. The teamwork framework presented in this chapter was implemented by the Faculty of Engineering and Information Technology's (FEIT) Teaching and Learning Laboratory (TLL) for the Infrastructure Engineering (IE) department. The TLL is a faculty-wide division that supports research-informed enhancements to learning and teaching in engineering and information technology through capability development and support for faculty staff. The IE department delivers seven Washington Accord-accredited master-level degree programmes, such as civil, environmental, and digital infrastructure engineering, and oversees several majors in undergraduate degrees. Undergraduate students typically complete a Bachelor of Science or Design with a relevant engineering major before progressing

to their chosen master programme in a 3+2 model of a 3-year bachelor and a 2-year master programme.

In our framework, we identified a taxonomy of effective teamwork behaviours across seven dimensions that should be demonstrated by an effective team member. While some of these behaviours are captured in this handbook's definition of teamwork (See Chapter 2.6 and the Glossary), others are more specific, or include skills from other categories, such as leadership or communication. In the following section, we present our definition of teamwork and connect it to the transferable competencies and skills defined in the earlier chapters of this handbook.

2 Competencies and skills development

In this section we present the key teamwork literature that we used to develop a working definition of teamwork, and the process we followed to synthesise that definition. In particular, we outline our overall approach to defining teamwork, key literature that has informed our definition, our taxonomy of teamwork behaviours, and the current iteration of our framework for teaching, practicing and assessing teamwork.

2.1 Creating a framework for teaching, practicing and assessing teamwork (TPAT)

In creating the Teaching, Practicing and Assessing Teamwork (TPAT) framework, we took a structured approach to defining what constitutes effective teamwork within the context of engineering education, as there was not a suitable existing definition, especially one that was designed for assessment in an engineering context. Our approach involved an extensive review of existing literature, consultation with module coordinators, and iterative refinement to ensure the definition was both practical and comprehensive.

The foundational literature underpinning our taxonomy and framework included Salas et al.'s work on the 'big five' in teamwork (2005), Boelt et al.'s (2023) thematic analysis of teamwork in problem-based learning, Chowdhury and Murzi's (2019) extensive review of teamwork in engineering education, the Comprehensive Assessment of Team Member Effectiveness (CATME) dimensions developed at Purdue University (Ohland, 2012), and the *Engineering thresholds: An approach to curriculum renewal* (Male, 2012). Additionally, we integrated insights from Engineers Australia's Stage 1 competency standards (Engineers Australia, 2019), which emphasize effective team membership and leadership skills, and Fletcher's (2015) work on gender, power, and relational work.

From this work we identified dozens of behaviours which we grouped into seven dimensions synthesised from the literature: adaptability, communication, coordination, collectivism, empathy, feedback, and leadership. We then refined the list by sharing and discussing it with academics who teach modules with significant teamwork elements. Tables 4.8.1 shows the final list of behaviours, which we mapped to the most relevant transferable competencies and skills based on the definition presented in Chapter 1.5.

*Table 4.8.1: Taxonomy of teamwork behaviours (Rios and Male, 2025), aligned to the transferable competencies and skills listed by Leandro Cruz & Saunders-Smits (2019). * = added during discussions*

<i>Taxonomy of teamwork behaviours</i>	<i>Transferable competencies and skills</i>
Adaptability	
Adjusts strategies when needed (Boelt, 2023; Male, 2012; Salas, 2005)	Innovation competencies: critical thinking, problem solving
Effectively deals with disruptions to team cohesion (Chowdhury & Murzi, 2019; Salas, 2005)	Teamwork competencies: managing conflict
Fills gaps in team skills as needed (Chowdhury & Murzi, 2019; Ohland, 2012; Salas, 2005)	Teamwork competencies: interdisciplinary collaboration
Maintains broad knowledge of team's goals and work (Salas, 2005)	Teamwork competencies: goal setting
Acquires new skills when needed to improve team performance (Chowdhury & Murzi, 2019; Ohland, 2012)	Lifelong learning competencies: actively seeking learning
Collectivism	
Prioritises team goals (Chowdhury & Murzi, 2019; Ohland, 2012; Salas, 2005)	Teamwork competencies: goal setting
Develops relational knowledge of team roles in context of operating environment (Boelt, 2023; Salas, 2005)	Teamwork competencies: interdisciplinary collaboration
Practices with mutual trust in each team member to fulfil their role and do excellent work (Chowdhury & Murzi, 2019; Ohland, 2012; Male, 2012; Salas, 2005)	Teamwork competencies: engagement in teamwork
Makes important contributions that improve the team's work (Chowdhury & Murzi, 2019; Ohland, 2012)	Teamwork competencies: engagement in teamwork
Helps teammates who are having difficulty (Ohland, 2012)	Teamwork competencies: engagement in teamwork
Participates fully in team activities (Ohland, 2012)	Teamwork competencies: engagement in teamwork

Communication

Practices active listening and closed-loop communication (Chowdhury & Murzi, 2019; Salas, 2005)	Communication competencies: listening skills
Communicates with respect (Boelt, 2023)	Communication competencies: adaptive communication style
Communicates using proper and agreed upon nomenclature (Boelt, 2023)	Communication competencies: adaptive communication style
Makes sure teammates stay informed and understand each other (Ohland, 2012)	Communication competencies: interconnection/interrelation ability
Uses diverse means of communication (drawings, writing, speech, etc.) as appropriate for the team	Communication competencies: quality of presentation method

Coordination

Takes into consideration others' time and availability (Boelt, 2023)	Teamwork competencies: time management
Communicates delays promptly. Monitors Progress (Boelt, 2023; Ohland, 2012)	Teamwork competencies: time management
Identifies and schedules team tasks and resource them appropriately as needed (Salas, 2005)	Entrepreneurial competencies: project management
Is punctual *	Teamwork competencies: time management
Maintains up to date records (e.g., calendar, project logs, other documentation) *	Entrepreneurial competencies: project management

Empathy

Recognises the value of and seeks out diverse viewpoints (Chowdhury & Murzi, 2019; Ohland, 2012; Male, 2012)	Teamwork competencies: cross-cultural understanding
Establishes a positive atmosphere (Chowdhury & Murzi, 2019; Salas, 2005)	Not present in list by Leandro Cruz & Saunders-Smiths (2019)
Is aware of and takes into consideration individuals' circumstance, position, background, or feelings (Male, 2012; Salas, 2005)	Teamwork competencies: cross-cultural understanding
Acknowledges the contributions of others (Fletcher, 2010)	Teamwork competencies: giving constructive feedback

Feedback

Provides constructive feedback to team members (Boelt, 2023; Chowdhury & Murzi, 2019; Ohland, 2012; Salas, 2005)	Teamwork competencies: giving constructive feedback
Seeks out feedback from peers (Boelt, 2023; Ohland, 2012; Salas, 2005)	Lifelong learning competencies: self-knowledge awareness
Critically reflects on received feedback (Chowdhury & Murzi, 2019)	Lifelong learning competencies: self-knowledge awareness
Take steps to improve based on feedback *	Lifelong learning competencies: actively seeking learning

Leadership

Directs and coordinates the activities of team members as needed (Boelt, 2023; Salas, 2005)	Entrepreneurial competencies: leadership
Motivates team members (Boelt, 2023; Chowdhury & Murzi, 2019; Ohland, 2012; Salas, 2005)	Entrepreneurial competencies: leadership
Fosters a collaborative and respectful culture within the team (Boelt, 2023; Chowdhury & Murzi, 2019; Salas, 2005)	Teamwork competencies: collaborative goal-oriented
Watches conditions affecting the team and manages the team progress (Boelt, 2023; Chowdhury & Murzi, 2019; Ohland, 2012; Salas, 2005)	Entrepreneurial competencies: project management
Alerts teammates and makes suggestions when problems arise (Chowdhury & Murzi, 2019; Ohland, 2012)	Teamwork competencies: managing conflict
Uses information available and sound judgement to make decisions (Boelt, 2023)	Innovation competencies: problem solving
Promotes the use of and defines processes of work (Chowdhury & Murzi, 2019)	Entrepreneurial competencies: project management

3 Implementation**3.1 Mapping and programmatic integration**

Once the teamwork definition was established, we drafted a mapping of when the behaviours should be attained across the programme. This mapping (Rios & Male, 2025), an excerpt of which is shown in Table 4.8.2, assigned behaviours to different year levels with the broad aim of introducing foundational skills in first and second

year and more advanced skills in third year and during the master programme. Concurrent with this, we surveyed every module in the programme to identify where students engaged in teamwork and whether it was taught, practised, or assessed. The survey findings helped us to pinpoint several core modules suitable for piloting the framework.

Table 4.8.2: Example behaviour mapping (Rios & Male, 2025)

<i>First year</i>	<i>Second year</i>	<i>Third year</i>	<i>End programme</i>
Collectivism			
-	-	Prioritises team goals	Prioritises team goals
Makes important contributions to the work	-	Collaborates on tasks when appropriate	Makes important contributions that improve the team's work
Takes on basic roles within a team (note taker, scheduler, leader, etc)	Identifies appropriate roles for a given project or group. Takes on one or more of these roles	Acknowledges the fluid nature of teamwork and adapts to new roles as the need arises	Develops relational knowledge of team roles in context of operating environment
Shares work evenly	Participates fully in team activities.	-	Participates fully in team activities
-	Helps teammates who are having difficulty	-	Helps teammates who are having difficulty
-	-	-	Practices with mutual trust in each team member to fulfil their role and do excellent work

Next, we held one-on-one meetings with academics teaching modules containing significant teamwork elements to gather targeted feedback on the draft mapping. Based on their input, we revised the mapping, moving some behaviours earlier or later in the sequence, adding progression levels where appropriate, and selecting three core modules to integrate the framework into. Selection was based on both academic buy-in and the suitability of the modules' teamwork activities and assessment structures for trialling the TPAT framework.

3.2 Supporting the framework

To support the adoption and implementation of the framework, we identified a range of teaching and learning activities along with exemplars that promote the development of teamwork skills and mapped these directly to the behaviours listed in the framework. We also identified possible assessment types suited to each behaviour, such as interviews, reflective writing, essays, and project logs. The purpose of these resources was to enable academics to independently choose approaches aligned with their module context.

In the initial stages, academics making changes to their modules were supported directly by learning designers, who provided guidance on designing and embedding teamwork-focused activities and assessments into the curriculum. Based on this work, we are currently building new resources, exemplars, and case studies that other academics can refer to when implementing their own changes without the need for significant additional support. These resources will serve as a practical reference for future academics, enabling them to design effective teamwork teaching and assessment activities that align with the TPAT framework without having to start from scratch.

It is important to note that much of the achievement in implementing the framework was possible due to the academic leadership of the programme. Their leadership was instrumental in creating buy-in and bringing together relevant and interested academics, while also putting forward one of their own modules for early adoption. At the same time, uptake has been slower than ideal due to this top-down approach, and as other priorities came up (e.g., a new assessment improvement project), it has been challenging to keep this project prioritised.

4 Curriculum design

In this section we discuss three case studies where we have used the framework to design the teaching, practice, and assessment of teamwork skills. Each case study highlights a different approach to using the framework, applied at a different level of study.

4.1 Case study 1: Engineering Technology and Society

Engineering Technology and Society is a first-year module that introduces students to engineering through a semester-long design project. Students work in teams of four, often for the first time in their academic journey, to collaboratively explore and address a societal issue, using engineering design principles. Recognising the foundational role this module plays in students' development, the teaching team used the TPAT framework to better structure and support the development of teamwork skills.

Motivation. This module has long had a comprehensive teamwork component, with group projects embedded in its curriculum since its inception. However, despite the extensive teamwork activities, the rationale and learning outcomes underpinning these activities were not always clear to students. Additionally, feedback from both students and staff indicated that although teamwork was being practised and taught,

its role as a professional skill requiring deliberate development was not sufficiently emphasised. The TPAT framework was adopted to provide a shared language for teamwork skills and to situate teamwork development within a broader professional learning trajectory.

Implementation. The TPAT framework was integrated into the module by mapping existing teamwork-related activities and assessments to the seven TPAT dimensions. The goal was to explicitly highlight to the students the teamwork skills they were developing and to encourage reflection on these behaviours as a key component of their professional formation. By doing this, the educators hoped that students would adopt a longer-term perspective on the development of their teamwork skills.

The TPAT framework was introduced in the second workshop of the semester, when student teams are formed. A presentation outlined each of the seven TPAT dimensions, along with examples of how module activities supported skill development.

Results. Integration of the TPAT framework into this module yielded promising outcomes. From the educators' perspective, it offered a structured language to explain the purpose behind teamwork activities, helping staff to clearly articulate expectations and learning goals, both to students and to each other. This clarity was especially valuable in a first-year context, where students are still developing their understanding of what it means to be an engineer.

Students responded positively to the early framing of teamwork as a professional skill and engaged meaningfully with the associated tasks. Use of project management tools such as Microsoft Teams was consistent across teams, and the team management plan prompted early discussion of team dynamics and expectations. However, reflections collected from teaching staff indicated that the delivery of the full TPAT framework in a single session may have overwhelmed some students. In future iterations of the module, coordinators plan to reinforce TPAT throughout the semester in smaller, context-relevant doses.

Importantly, the TPAT framework provided a way for students to begin understanding teamwork as a transferable skill. Several students expressed appreciation for seeing how their teamwork experience fitted into a broader developmental arc, and staff observed a shift in how students approached collaboration, with more attention paid to team roles, communication, and self-awareness.

4.2 Case study 2: Applying Digital Infrastructure

Applying Digital Infrastructure is a second-year project-based module, where students collaborate in teams of four on an eight-week engineering project. The project mirrors real-world professional practice, including both a tender and delivery phase. Historically, while teamwork was expected in this module, it lacked explicit structure and guidance, leading to mixed outcomes.

Motivation. As in many modules, teamwork in this module suffered from challenges in team dynamics and uneven contributions from students. Academics in the module also

noted that students were underprepared to manage complex teamwork scenarios, especially under time constraints, which resulted in late submissions and disengaged team members. While the technical aspects of the project were well scaffolded and appropriate for the year level, the teamwork was not, nor was it taught or specifically assessed. As such, the module coordinator hoped to use the TPAT to frame the expected skills and behaviours students should start to develop at this stage of their journeys, particularly in active group management.

Implementation. To address the above concerns, specifically concerns about students' leadership, collectivism, coordination, and communication skills, the module coordinator implemented the following changes.

Group formation activities. New group formation activities were designed to encourage early discussions of what effective teamwork looks like, and how challenges could be resolved. As well as icebreaker activities, these also included discussions of real-world teamwork case studies.

Team charter. After group formation, students created a team charter. In this activity students first reflect on their individual strengths, weaknesses, and skills before asking a series of structured questions addressing the team roles, norms, conflict management strategy, communication channels, and expectations. Language from the TPAT framework was used to communicate expectations of effective teamwork behaviours. The team charter existed as a living document and was reviewed twice over the semester after key milestones. During each review phase, students were encouraged to discuss the project so far, any issues that may have arisen and if their solution was effective. After this, students updated their charters if necessary and noted any changes in a teamwork management journal, which formed part of the final assessment.

Structured discussion assessment. The module culminated in an interactive oral assessment that takes the form of a performance review discussion with their project supervisor, counting for 25% of the final mark. During the discussion, students were asked to reflect on their experience of teamwork management and highlight their key takeaways from the process.

Result. The implementation of TPAT in this module produced several tangible outcomes that reflected its effectiveness in enhancing teamwork learning. Notably, all student groups successfully met project deadlines during both the tender and delivery phases, with only one of thirty teams reporting a major issue related to uneven contributions. This marked a significant improvement over previous offerings of the module, where late submissions and disengaged team members were more common.

Student reflections and responses to a voluntary end-of-semester survey indicated a shift in how students understood and approached teamwork. Many students reported developing a stronger awareness of teamwork processes, including coordination, communication, and shared responsibility. They described gaining practical experience in handling team dynamics, resolving conflicts, and appreciating the diverse perspectives and strengths that peers brought to the group. Students also highlighted

learning to manage group time effectively and delegating tasks equitably as skills they had gained.

While some students initially saw the group charter as a formality, others later acknowledged its value in setting clear expectations and serving as a reference point for navigating group challenges. The activity also promoted early team cohesion and encouraged students to reflect on their own contributions.

From the educators' perspective, the TPAT framework offered a practical tool for embedding teamwork more explicitly within the curriculum. It provided a shared vocabulary and structured approach for teaching and assessing teamwork behaviours, allowing staff to give more targeted and meaningful feedback. Overall, staff observed greater student ownership of group processes and a more professional mindset in how students engaged with the teamwork components of the module.

4.3 Case study 3: Interdisciplinary Design for Engineers

Interdisciplinary Design for Engineers is a compulsory module for all Master of Engineering students. This module focuses on developing students' transversal skills, in particular, communication, empathy, and teamwork, while teaching the principles of engineering design in the context of an interdisciplinary design project. The cohort consists of students from all engineering disciplines within the faculty including biomedical, chemical, civil, digital infrastructure, electrical and electronic, environmental, mechanical, mechatronics, and software engineering.

Motivation. This module was developed from the ground up with the TPAT framework in mind. At the master level, students are expected to enter the workforce with well-developed teamwork and communication skills, yet feedback from academics and industry consistently highlights variability in these competencies. Given the interdisciplinary nature of the module, teams are composed of students with highly diverse disciplinary knowledge, cultural backgrounds, and professional experiences, making it an ideal environment to intentionally develop and assess teamwork behaviours. The motivation was twofold: firstly, to provide explicit scaffolding for teamwork in a high-stakes, capstone-style design module; and secondly, to evaluate how the TPAT framework could be applied to support advanced-level teamwork in mixed-discipline cohorts.

Implementation. At the design stage, the teaching team identified the specific teamwork dimensions to prioritise for this module. Empathy, leadership, and feedback were chosen as the primary focus areas, in part because of their strong alignment with the module's interdisciplinary design learning outcomes. Language and behavioural descriptors from the TPAT framework were used to create rich, transparent descriptions for the assessment criteria.

The duration of the module was 12 weeks, with two 2-hour workshops per week. Three of these workshops were dedicated entirely to teamwork. The first workshop introduced team formation strategies, leadership principles, and empathy-building activities. The second focused on effective communication and feedback within the context of a team, and the final teamwork session was a self-directed activity in which

groups revisited their team charters and engaged in a scaffolded reflection on their collaborative processes.

Teamwork was assessed through multiple complementary measures: group reflections embedded in mid- and end-of-semester reports, peer feedback on oral presentations, an interactive oral assessment in the form of a group discussion, and an end-of-semester individual reflection. These were triangulated with educator observations and fortnightly project progress journals to provide a well-rounded view of each student's teamwork development.

Results. Overall, the introduction of the TPAT framework into this module was associated with positive teamwork outcomes. No significant group issues persisted beyond the assessment submission dates, suggesting that teams were able to resolve challenges effectively before they impacted deliverables. Student feedback frequently highlighted the value of the structured opportunity to develop and practise teamwork skills, with many noting that the interdisciplinary context broadened their perspective and enhanced their collaborative abilities.

From the teaching team's perspective, the implementation revealed areas for further enhancement. In particular, giving and receiving feedback — while addressed — could be more strongly embedded within assessment tasks to emphasize its importance and provide students with more practice in this skill. Looking ahead, there are plans to strengthen the triangulation of teamwork assessment through the inclusion of peer evaluation tools such as CATME and the use of more observational and interactive oral assessments, enabling more robust, multi-source evidence of teamwork behaviours.

5 Future outlook

The TPAT framework can be used as both a curriculum design tool and a review instrument to ensure that teamwork skills are systematically developed across a programme. At an institutional level, programme directors can begin by mapping existing modules against the framework's seven dimensions — adaptability, feedback, communication, coordination, collectivism, leadership, and empathy — to identify where each behaviour is introduced, practised, and assessed. This mapping helps reveal gaps, redundancies, and opportunities for more even scaffolding across year levels. Institutions may also integrate the framework into programme-level learning outcomes, aligning it with accreditation requirements and transversal skill definitions to ensure coherence across disciplines.

At the module level, academics can use the framework to design new learning activities, refine existing teamwork components, and select appropriate assessments for targeted behaviours. For example, they might align a peer assessment activity with the feedback dimension or develop a team charter exercise to support coordination and collectivism. The framework also serves as a communication tool to help students see the progression of their teamwork skills across their degree, fostering long-term professional skill development rather than treating teamwork as isolated to specific projects.

Finally, the framework continues to be developed by adding more supports, resources and instructions for academics looking to use the framework. Currently we are developing principles for designing assessments using the framework. Additionally, the framework will be further supported by a catalogue of case studies showcasing how other academics have used the framework in their curriculum.

SWOT analysis

In this Section, we present a short strengths, weaknesses, opportunities, and threats (SWOT) analysis to summarise the key benefits and challenges of the TPAT framework.

Strengths

- *Clear, programmatic structure.* Defines seven core teamwork dimensions with observable behaviours mapped across the degree programme, ensuring skill development is scaffolded.
- *Evidence-based foundation.* Developed from a comprehensive literature review and aligned with both industry expectations and accreditation standards (i.e., Engineers Australia Stage 1 Competency Standards).
- *Flexible implementation.* Can be used both for curriculum design and review, allowing module coordinators to adapt activities to their context.
- *Alignment with employability frameworks.* Positions graduates with demonstrable, industry-valued teamwork skills.

Weaknesses

- *Initial complexity for students.* Full framework presentation can overwhelm first-year students, suggesting a need for staged introduction.
- *Variable academic engagement.* Implementation relies heavily on coordinator willingness and capacity; without strong buy-in, uptake may be inconsistent.
- *Assessment not yet fully developed.* Current focus is on defining and mapping skills; robust, scalable assessment tools for each behaviour are still under development.
- *Resource dependency.* Successful integration requires supporting materials, guides, and professional development, which are not yet fully available.

Opportunities

- *Scaling across programmes and faculties.* Potential to embed in all engineering programmes, creating a unified approach to teamwork skill development.
- *Cross-institution collaboration.* Opportunity to share the framework and resources with other universities, contributing to best practice in professional skills education.
- *Longitudinal tracking.* Can be used to collect data on student skill progression across their degree, informing curriculum improvement and accreditation reporting.

Threats

- *Perceived curriculum overcrowding.* Competing priorities in degree programmes may be perceived to limit time and resources for explicit teamwork skill development when a siloed approach is taken.
- *Inconsistent application.* Without central oversight, variations in implementation could dilute programme-wide impact.
- *Assessment challenges.* Measuring behavioural competencies reliably across varied contexts may be difficult, risking credibility if poorly executed.

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AI statement

During the preparation of this work, the authors used ChatGPT to obtain feedback on and self-review our first draft. Based on the feedback from the AI tool we then made minor edits to adjust grammatical and structural issues. After using this tool, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

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4.9

Embedding Transferable Competencies and Skills in Engineering Curricula: A Comparative Case Study of the University of Sydney and the University of Technology Sydney

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This chapter presents a comparative review of whole-of-degree approaches to embedding transferable competencies and skills in accredited engineering programmes at the University of Sydney (USYD) and the University of Technology Sydney (UTS). This analysis draws on two decades of experience in programmes enrolling 6,500-8,000 students. It examines sustained, coherent, and durable approaches to embedding transferable competencies and skills over time. The discussion identifies four design principles: curriculum-wide embedding, progressive scaffolding, authentic contextualisation, and evidence-informed assessment. It analyses how these principles are enacted through contrasting structural models: UTS's dedicated five-unit core sequence and USYD's distributed integrated units combined with a co-curricular professional engagement framework. While structurally different, both models achieve programme-level outcomes, including curriculum coherence, institutional resilience, and long-term sustainability. Beyond curriculum design, the chapter highlights governance and change management as central to success. It identifies persistent challenges such as alignment drift, stakeholder resistance, and resource sustainability. The study presents insights related to programme governance, coordination, and continuous improvement. The chapter demonstrates that sustained institutional commitment and explicit governance structures — rather than any single structural model — are critical to embedding transferable competencies and skills without compromising technical excellence.

1 Introduction

This chapter examines how the University of Sydney (USYD) and the University of Technology Sydney (UTS) integrated transferable competencies and skills across their accredited engineering programmes. Both universities serve large cohorts and have implemented whole-of-degree approaches across multiple engineering disciplines.

Critically, both are mature programmes that have undergone multiple iterations over more than a decade, providing insights into the full lifecycle of embedding transferable competencies and skills — including teamwork, communication, ethical practice, and sustainability — from initial implementation through to sustained operation. This maturity brings challenges to the fore that only emerge over time: maintaining programme coherence through changing institutional priorities and leadership, managing staff turnover, building support across multiple stakeholders, adapting to evolving accreditation requirements and industry needs, and sustaining quality through continuous programme renewal.

The chapter situates both programmes within their educational context, before presenting the structural design of each approach through paired case studies. It then examines the shared pedagogical principles underpinning both models and how each institution translates these into practice. The chapter explores the change management processes required to implement and sustain these frameworks through further institutional case studies. The chapter concludes with a review of key enablers, ongoing challenges, and practical recommendations for educators undertaking similar reforms. Thus, it contributes to the literature on curriculum-wide approaches to transferable competency and skill development (see Crawley et al., 2014).

2 Educational context

The engineering programmes at USYD and UTS operate within the Australian Qualifications Framework (AQF), which parallels the European Qualifications Framework (EQF). Both institutions deliver Bachelor of Engineering Honours degrees (AQF Level 8, comparable to EQF Level 7) and Master of Engineering programmes (AQF Level 9, comparable to EQF Level 8), all accredited by the national accreditation body, Engineers Australia (EA). USYD has ca. 8,000 engineering students while UTS has ca. 6,500 engineering students.

Both institutions have responded to sustained industry demands for graduates with strong transferable competencies and skills (Crosthwaite, 2021; King, 2008) by integrating these throughout the curriculum. This involved moving beyond a focus on technical knowledge alone to encompass the broader competencies emphasised in qualification frameworks like the EQF. Distinctly different implementation structures have been used to achieve these goals.

The EQF emphasises intentional integration and progression. It highlights the importance of scaffolding, so students encounter, practise, and reflect on their development at increasing levels of sophistication. Engineering programmes typically integrate transferable competencies and skills through one of two broad approaches:

dedicated standalone units that teach competencies explicitly, or distributed integration where competencies are embedded across disciplinary units. The choice of approach is influenced by institutional priorities, accreditation requirements, and available resources. Many engineering programmes adopt hybrid strategies to maximise contextual relevance and skill transferability (Male et al., 2011; Walther et al., 2011). Both UTS and USYD adopt hybrid approaches: transferable skills are scaffolded through dedicated units alongside the disciplinary curriculum, but the tasks within those units require students to apply technical engineering knowledge across disciplines. This ensures transferable competencies and skills are developed in context rather than in isolation. At UTS, core units foreground transferable competencies and skills as explicit learning objectives while embedding them in tasks drawing on technical knowledge from students' engineering specialisations — for example, communication is addressed in the context of responding to tender requests. USYD ensures no skill is taught in isolation; competencies are woven into progressively complex project tasks — for example, teamwork is not addressed as a standalone topic but scaffolded as an essential element of larger project delivery.

The following two subsections describe the structural design of each institution's approach. Programme maturity has meant that transferable competencies and skills are an accepted curriculum component. Once the principle is established, the programme becomes sustainable at least until the next major curriculum review.

2.1 The UTS approach: an engineering core

UTS centralises transferable competency and skill development in a dedicated five-unit core sequence (ca. 15% of the engineering degree in time allocation and course credit), ensuring all students across every engineering discipline receive consistent, explicitly scaffolded competency development regardless of technical specialisation. UTS judged these competencies and skills warranted dedicated curriculum space — both as a matter of educational priority and because explicit positioning communicates to students and staff that these capabilities are fundamental to engineering practice, not an adjunct to it.

All core units incorporate a multidisciplinary focus, requiring engineering majors to work together. Each unit builds on the previous, providing progression from foundational to advanced competencies.

The core sequence is closely tied to the Professional Engagement Program. This programme guides students through preparation for, participation in, and reflection on, mandatory industry placements (internships, which receive academic credit and are usually paid). It ensures transferable competencies and skills developed in the classroom are applied, tested, and developed in industry settings, supporting the transition from student to engineer.

A typical structure for the four-year degree is illustrated in Fig. 4.9.1 (unit timing varies by specialisation; labels indicate typical degree position). Australian universities operate on a February–November academic year with two main teaching periods

(semesters). The normal undergraduate engineering programme is four years. The subjects below are indicated in Fig. 4.9.1 as the “Core Program”.

- *Year 1.* Introduction to Engineering Projects: fundamentals of teamwork, design thinking, communication, and collaborative project work in a real-world context. This unit lays the foundation for reflective and effective engineering practice and is typically taken in Semester 1 of first year.
- *Year 2.* Engineering Project Appraisal: economic and sustainability evaluations of engineering projects, applying critical thinking and ethical practice. The focus is on using frameworks to appraise project decisions.
- *Mid degree.* Designing Sustainable Engineering Projects: interdisciplinary teams address real-world sustainability challenges through integrated analysis and reflective practice to design impactful solutions.
- *Year 3.* Professional Engineering Communication: project management, financial considerations, critical thinking, and workplace communication through the context of tendering.
- *Final year.* Collaboration in Complex Projects: a ‘capstone’ core unit consolidates teamwork and stakeholder engagement in real-world design projects requiring consideration of commercial, environmental, social and Indigenous perspectives.

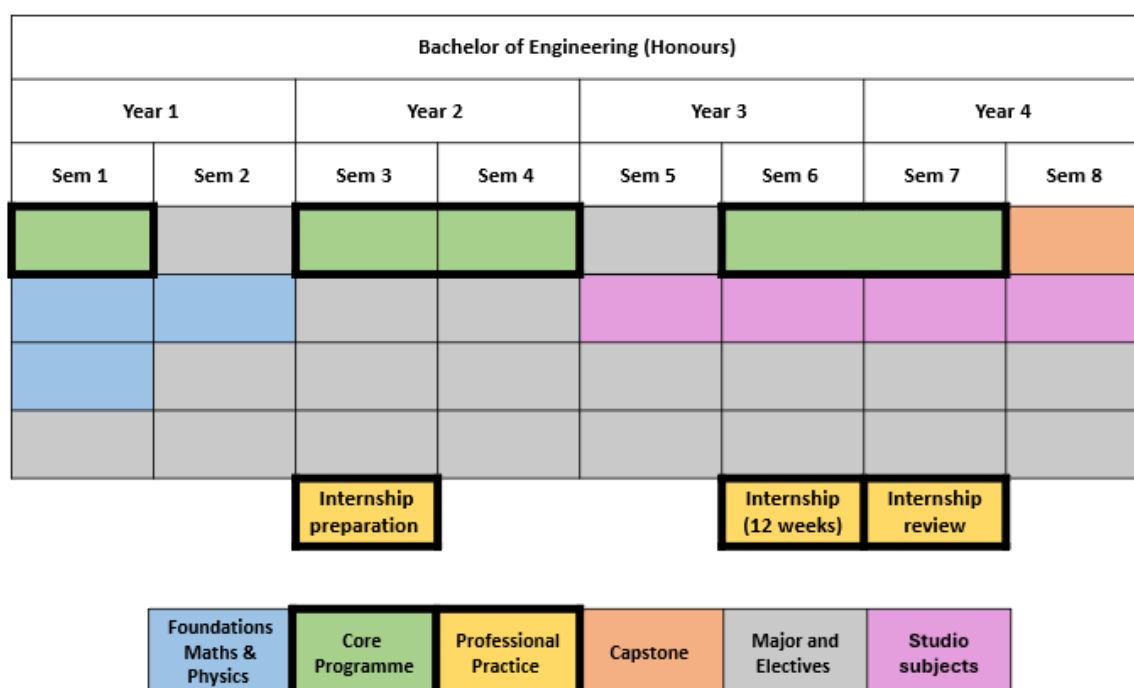


Figure 4.9.1: Typical degree structure for four-year engineering degree
(Own Work by Tania Machet, 2025)

Students may also enrol in the optional Diploma of Professional Practice, which replaces the mandatory industry placements with two extended six-month placements in Years 2 and 4, supported by preparatory and reflective units developed in

consultation with industry. The programme culminates in a discipline-based industry event at which industry representatives view students' work and meet students, providing networking opportunities and supports career progression. These are illustrated as the "professional practice" subjects in Fig. 4.9.1.

2.2 USYD approach: integrated framework

USYD combines two components to deliver transferable skills across the programme: the Integrated Engineering Program (IEP) and the Programme (PEP).

IEP

The IEP was designed to provide a staged development of transferable skills with continued exposure throughout the degree programme. The initial implementation was four core-curriculum units across all degree years. The programme began with foundations of professional engineering and design thinking in Year 1, building progressively in complexity and breadth through Years 2 to 4.

From Year 2, IEP units, taken in addition to a standard study load, involved multidisciplinary collaboration across specialisations, providing opportunities for students to integrate knowledge and methods from different disciplines. Projects moved from basic project management skills and project opportunity responses, to identifying a project client and opportunity, to analysing organisational context and stakeholders to recommend change.

IEP was revised in 2021 to comprise three larger units positioned within a standard study load. This enabled delivery of more substantial project experiences with an emphasis on multidisciplinary capability and transferable competencies.

1. *Year 1.* Introduction to discipline: students develop disciplinary identity through well-defined single discipline problems.
2. *Year 2.* Multidisciplinary engineering: project management and data-driven decision making through multidisciplinary project teams.
3. *Year 3.* Interdisciplinary engineering: client engagement, problem formulation, and project leadership. Students undertake interdisciplinary, externally sponsored, and ill-defined projects requiring diverse engineering competencies, plus methods drawn from outside engineering.

PEP

The PEP was designed to encourage and recognise diverse forms of exposure to professional practice, beyond traditional internships. It was structured as a co-curricular requirement (i.e., compulsory, but existing outside the conventional requirement of completing specified individual modules within semester constraints) where students must independently complete 600 hours of activities, comprising:

- Engineering-focused activities (minimum 200 hours) – e.g., attending industry seminars, completing an industry project, hackathon or competition, etc.
- Transferable competencies development (minimum 70 hours) – e.g., leadership within a volunteer association, casual employment, online courses, etc.

- Engineering work experience (minimum 200 hours) – e.g., employment in an engineering internship

This dual approach to curricular and co-curricular professional competencies provides structured integration and flexible professional development opportunities tailored to individual students.

Despite different structural implementations, both institutions arrived at their chosen approach through a common recognition: that transferable competencies and skills would not develop reliably without close oversight across all engineering discipline programmes on offer. The following sections examine the shared pedagogical principles applied within these different structures, the change management required to implement them, and the challenges encountered along the way.

3 Approach to competency and skill development

USYD and UTS develop transferable competencies and skills aligned with established frameworks for competency progression in engineering education (Crosthwaite, 2021; Male et al., 2011), while addressing the challenges of implementation at a large scale (Graham, 2012). Despite different implementation approaches, the universities share several design principles:

- Embedding competencies across the curriculum;
- Adopting progressive scaffolding and assessment moving students from foundational to advanced levels of competency, supporting independence, increasing agency, and responsibility;
- Emphasising authentic contexts integrating technical and professional capabilities;
- Analysing level of cohort learning outcome achievement to drive learning delivery decisions, activity design, and assessment.

The following sections examine each principle, discussing its rationale and pedagogical foundations with illustrative case studies.

3.1 Whole-of-curriculum integration

Both universities integrate transferable competencies and skills throughout their curricula. This approach is supported by evidence that integrated competencies are valued by industry (Male et al., 2011) and improve transfer to professional practice (Winberg et al., 2020). The approach allows students to experience these capabilities as essential to engineering work. Despite structural differences, both approaches ensure students repeatedly encounter, practise, and refine transferable competencies and skills (abilities applicable across diverse sectors and life situations) in increasingly complex engineering contexts.

3.2 Progressive development through the degree

Transferable competencies and skills require systematic scaffolding, practice (application), and feedback to move students from foundational understanding to advanced application.

This requires students to receive different levels of support at different stages. Early in their studies, students need clear instruction, structured activities, and significant feedback to understand and use these competencies. As students gain experience, academic support is replaced with increased internal and peer feedback. Internal feedback, generated from self-monitoring, helps students to adjust strategies and performance, which is central for self-regulated learning (Butler & Winne, 1995). This adaptive support mirrors professional development where practitioners move from supervised practice to independent application.

3.3 Authentic contexts

Authenticity is contextual and cannot be defined by a fixed checklist. It is better understood as aspirational principles focused on real-world learning and assessment that develop the attributes and competencies students need for their future learning and work (Sokhanvar et al., 2021; Villarroel et al., 2018). Effective authenticity incorporates the complexity of real-world contexts (Lombardi, 2007) through experiential, student-centred learning rather than replicating problematic or inconsistent workplace conditions. This provides students with meaningful challenges requiring both technical and professional competencies, helping them understand how these operate together in engineering practice.

However, authenticity alone is insufficient. Without assessment that genuinely measures the intended competencies and structures that hold students accountable for their own learning, authentic tasks risk becoming performative (Villarroel et al., 2018). Assessment must be designed to capture evidence of genuine competency development. In universities, incorporating the complexity of real-world contexts may be overwhelming for students lacking the competencies to manage multidimensional problems. This may lead to student resistance, poor satisfaction (Brookfield, 2017), and unproductive use of time. Clear scaffolding, including learning theories explaining the intended approach, expected experiences, and evaluation of learning and achievement, is required for success (Willey & Gardner, 2012).

3.4 Evidence-based learning and assessment

Using learning outcome achievement to drive curriculum design represents a commitment to evidence-based education, including assessment that captures the complexity of transferable competencies and skills while maintaining validity and reliability. It demands assessment and feedback systems that support and develop student learning. Assessment fidelity evaluates how students learn, think, and develop their work, not just their final product. Feedback should help students understand and identify areas for continued development (Carless & Boud, 2018).

Both universities use structured self- and peer assessment to facilitate evidence-based assessment and feedback. Thus, they maintain a cycle of judgement, feedback, and reflection that could be implemented through various tools or carefully designed manual processes. As an example, both institutions use SPARKPLUS, a web-based platform that collects evidence of task contribution and collaborative processes and can also convert group marks to individual marks reflecting individual contributions.

Iterative self- and peer assessment promotes reflection, improves academic honesty, increases student motivation, and develops feedback literacy, all of which model the professional practice students are being prepared for (see SPARKPLUS, n.d.).

The following examples examine how the shared principles above are translated into practice, summarised in Table 4.9.1. UTS takes a taxonomy-driven approach, using a curriculum framework to map skills across all four years. USYD centres its approach on progressively increasing the authenticity and complexity of student engagement with professional practice.

Example 1. UTS implementation of shared principles

Integrating in whole-of-degree

UTS integrates transferable competencies and skills through the core units, then reinforces them across discipline units. For example: project management concepts, business, and ethics are taught and assessed in Year 2 (Engineering Project Appraisal), practised in Year 3 (Designing Sustainable Engineering Projects), become prerequisite knowledge for studios in discipline units, receive deeper teaching and assessment in Year 4 (Professional Engineering Communication), and are applied in the final core unit (Collaboration in Complex Projects). This ensures competencies are developed in multiple contexts rather than as isolated learning.

Progressive development and scaffolding

UTS operationalises progressive improvements through its Curriculum, Assessment and Learning Framework (CALF), a taxonomy that maps transferable skills through three developmental stages: Foundational, Developing, and Pre-professional. For example, teamwork competencies are taught, developed and assessed across three units and the CALF levels articulated in the following learning outcomes:

- Year 1 (foundational): explain the collaboration and contributions of team planning, communication and problem solving in developing a design solution.*
- Mid-degree (developing): apply relational teamwork competencies to complete a group project.*
- Later-year (pre-professional): collaborate with stakeholders in diverse interdisciplinary teams to achieve problem solutions.*

Scaffolding is reduced and student responsibility increases in subsequent years.

Authentic real-world contexts

UTS achieves authenticity through 'scaffolded realism': workplace contexts may involve power imbalances, time pressures, or learning-inhibiting environments. Rather than exposing students to problematic conditions, UTS provides professional challenges within supportive educational frameworks, maintaining scaffolding. One example of this graduate exposure to authentic practice is engagement with Indigenous communities, an explicit priority in Australian engineering education reflecting national reconciliation commitments and accreditation expectations.

Students work on community-identified problems in Year 1 and again in Year 4, with interactions structured and facilitated by teaching and staff mediated through partner organisations with established community relationships. This allows students to learn from mistakes without harming community relationships, while developing cultural capability.

Evidence-based learning and assessment

UTS ensures assessments evaluate intended learning outcomes in authentic professional contexts. Year 4 Professional Engineering Communication uses real tender documents and procurement processes. Students submit a written tender response and deliver an oral pitch to a panel that includes industry representatives, demonstrating communication competencies within the same contexts as practising engineers. This industry-based approach extends to the professional practice programme, where students are graded complete/incomplete, mirroring workplace expectations. Tasks may require multiple iterations before completion, and feedback is deliberately direct: in the final career interview, for example, instructors are encouraged to identify the exact moment a hiring decision would be made.

Example 2. USYD implementation of shared principles

Integrating in whole-of-curriculum

USYD's intent is to integrate transferable competencies and skills through credit-bearing, project-based learning distributed across the degree. This is supported by a longitudinal co-curricular programme. Integration is achieved through the Integrated Engineering Program (IEP): three compulsory project units (ca. 13% of total credits of the degree) delivered across the first three years, complemented by the Professional Engagement Program (PEP) spanning all four years. From Year 2, IEP units require multidisciplinary teamwork, ensuring professional capabilities are developed alongside technical knowledge. In contrast to UTS's dedicated core sequence, USYD distributes skill development across both integrated project units and co-curricular activity.

Progressive development and scaffolding

Progressive development is operationalised through increased project scope and responsibility. In Year 1, students undertake well-defined, discipline-based projects teaching teamwork, communication, ethical practice, and reflection. Learning is supported through structured templates, exemplars, and guided reflective prompts. In Year 2, students complete externally sponsored multidisciplinary projects (e.g., data modelling addressing societal challenges), requiring negotiation of roles, collaborative decision making, and stakeholder-aware communication. In Year 3, students engage in ill-defined, interdisciplinary projects involving industry, government, or community partners, highlighting problem formulation, leadership,

and integration of multiple considerations. PEP scaffolds development in parallel, from early industry engagement to a compulsory industry internship.

Authentic real-world contexts

USYD achieves authenticity across the degree through project- and team-based learning challenges supported by external industry or community partners but delivered within the institutional setting. This allows students to practise professional behaviours in realistic but supported contexts rather than replicating unmanaged workplace conditions.

Evidence-based learning and assessment

Transferable skills are assessed through aligned, explicit assessment modes. These include project artefacts (e.g., mock trade exhibitions, technical reports, design documentation, stakeholder briefings), structured peer and self-assessment of teamwork, and reflective assessments requiring students to evidence professional judgement. Feed-forward assessment is used throughout: formative feedback on proposals, interim reports, and presentations are addressed in subsequent submissions, enabling demonstration of developing competence over time.

Table 4.9.1: Comparison of UTS and USYD implementation of shared principles for approach to competency and skill development

<i>Shared principle</i>	<i>Similarity</i>	<i>How this is operationalised</i>
<i>Whole-of-curriculum integration</i>	Both integrate transferable competencies and skills across the full four-year degree.	UTS uses a sequence of core units; USYD uses dedicated units paired with a parallel professional engagement programme.
<i>Progressive development and scaffolding</i>	Both reduce scaffolding and increase complexity year on year.	UTS uses a defined skill taxonomy (CALF); USYD expands project scope and stakeholder complexity progressively.
<i>Authentic real-world contexts</i>	Both balance authenticity with appropriate student support.	UTS maintains a consistent scaffolded framework; USYD increases authenticity as student capacity develops.
<i>Evidence-based assessment</i>	Both align assessment with authentic professional contexts.	UTS uses professional artefacts and peer assessment; USYD uses feed-forward structures. Early feedback informs later assessments.

While these principles and their implementation are essential, equally important is understanding the change management required to establish such comprehensive programmes.

4 Change management requirements

Both programmes required substantial institutional transformation to implement change, and both institutions drew on external drivers to support this change. Engineers Australia accreditation requirements ensured compliance with competency standards, while industry advisory boards validated the approach, offering insights into graduate skill gaps and endorsing solutions.

Yet even with these external drivers supporting change, several challenges emerged during implementation. This chapter traces the journey both institutions underwent in three stages: confronting initial resistance, discovering the hidden challenges, and building the structures needed for long-term programme integrity. We offer practical insights for educators planning similar reforms.

4.1 *The initial challenge: confronting resistance and building value*

Implementation faced resistance from multiple stakeholder groups, such as students and some academic staff who felt that technical expertise was more highly valued than transferable competencies and skills (at least as an initial priority for employment); colleagues who felt that any focus on transferable skills was a threat to the 'curriculum real estate' available to their own teaching focus; and staff who were concerned about possible negative reactions from students.

Success depended on senior leadership support and teaching and administrative staff who understood and supported the redesigned curriculum. The change management challenges encountered echo those documented in other curriculum reform initiatives, requiring both top-down support and bottom-up engagement (Borrego & Henderson, 2014).

Beyond resistance from individuals, both institutions encountered resistance from institutional systems. The complexity of university programmes imposed constraints related to unit progression, credit point allocations, and timetabling requirements. Transition required teaching out old units whilst recruiting staff, creating temporary resource strains.

Addressing this resistance required repeated communication of learning outcomes, industry expectations, and accreditation requirements. In the early years, before graduate outcomes data was available, both institutions relied primarily on accreditation requirements and industry advisory board endorsement to justify the programmes, using external professional authority as a proxy for the employment evidence that accumulated over time. Resistance decreased as the programme's value became visible and its 'newness' faded. Student opposition dropped after the second running of each unit, as separation between cohorts working through old and new programmes increased.

4.2 The hidden challenge: discovering and preventing alignment drift

A critical lesson was the need to prevent 'alignment drift': the gradual loss of programme coherence that occurs when complex, multi-year programmes operate without ongoing attention.

Through experience, both institutions identified four key requirements for preventing loss of programme coherence:

- *Ongoing programme management.* Dedicated resources for continuous monitoring and coordination across units and years, including team-based preparation of unit revisions and checking of assessment outcomes;
- *Regular curriculum mapping reviews.* Systematic checking that learning outcomes are still met and that competency progression remains coherent;
- *Staff development and communication.* ensuring teaching staff understand their role in the broader programme rather than just their individual units;
- *Student feedback integration.* regular collection and analysis of student experiences to identify where the programme may be losing coherence. This also included evaluation of alumni feedback.

Addressing this curriculum coherence loss required the establishment of durable institutional structures, as discussed below.

4.3 The ongoing challenge: embedding sustainable structures

Administrative support proved critical for managing transition logistics. Recognition of prior learning was particularly challenging. These programmes distribute competencies across multiple units at increasing levels of sophistication, unlike traditional structures where a single unit covers a discrete skill.

Workload allocation remains an ongoing challenge. Curriculum integrity requires sustained institutional attention, not merely periodic review. Both institutions established dedicated teaching teams and ongoing professional development to maintain quality and coherence.

Sustainability also requires acceptance that refinement is a permanent feature of programme management. Both universities recognised that the first iteration would not be perfect. Both institutions build continuous improvement into their governance structures, with teaching teams regularly reviewing evidence from student feedback and assessment outcomes to drive programme refinement.

Each new cohort encounters the programme without the benefit of having watched it evolve, and questions about the value of 'non-technical' units resurface regularly. Consequently, both institutions found that proactive communication strategies including clear articulation of learning outcomes, visibility of industry endorsement, and peer testimony from students are needed on a recurring basis rather than as a one-off response to resistance. Managing this ongoing scrutiny is a permanent feature of programme stewardship, not a transitional challenge.

Sustaining these programmes requires ongoing attention to academic staff culture. Resistance may diminish over time, but this does not automatically translate into engagement with whole-of-degree goals. Building a staff culture where academics see themselves as contributors to a broader learning journey requires deliberate, ongoing investment beyond one-off professional development. At UTS, this shift has been supported by a shared sessional teaching team, in which the same staff run the small-group classes of large-cohort subjects throughout the programme, building continuity and shared ownership of programme-level goals, together with fortnightly team meetings; at USYD, the IEP and PEP structures have created opportunities for cross-disciplinary collaboration.

4.4 The response: how each institution navigated these challenges

The examples that follow illustrate how each institution navigated the three outlined stages in practice, and the specific strategies each employed to reach their current level of programme maturity. Example 3 examines UTS's comprehensive programme-level redesign, while Example 4 focuses on one component of USYD's reform — the introduction of the PEP — to show how similar change management challenges emerged and were addressed within a co-curricular context.

Example 3. UTS: Managing large-scale curriculum reform

Identifying the need for change

Initially introduced in 2000, by 2022 UTS identified significant 'alignment drift' in its core programme. New academic staff taking over individual units had updated content to reflect current industry standards with limited visibility of changes across the programme. Units that once built upon each other became disconnected. When coordinators began collaborating, they discovered units no longer aligned. Student feedback revealed confusion about skill evolution and unit connections. Industry advisory board input suggested addressing misalignment with workplace expectations. Additionally, an accreditation review and the Australian Council of Engineering Deans' Engineering Futures report (Crosthwaite, 2021) highlighted the need for more coverage of competencies such as sustainability and ethics.

Rapid redesign under institutional constraints

Faculty Teaching and Learning leadership initiated a programme review in May 2022, with a requirement that students commence the redesigned programme the following year. This compressed the review and redesign cycle to fourteen months. The foundational core unit was retained — it already aligned with the embedded transferable competencies framework, reducing the redesign burden. Implementation then proceeded iteratively, with remaining units introduced progressively and refined as student feedback was collected.

Stakeholder engagement strategy

UTS established a team of academics, championed by faculty leadership. They employed a design thinking approach, developing an initial framework for embedded competencies through collaborative ideation sessions. This was followed by stakeholder consultation using focus groups with prepared materials and focused questions to elicit feedback. Stakeholders included industry representatives, current students, academic staff from each engineering specialisation, and colleagues from double degree programmes. Communication was sustained through iterative design workshops, validation sessions, and stakeholder review meetings.

Managing multi-source resistance through strategic interventions

Some in the engineering disciplines resisted the redesign, pushing for the inclusion of discipline-specific technical content — such as programming or big data — rather than transferable competencies. UTS maintained focus on competencies relevant across all specialisations and actively involved discipline teams in developing field-specific exemplars and case studies. This transformed resistance into engagement and created intellectual ownership of the redesigned content.

Administrative personnel experienced increased workload from programme transitions and the complexity of recognition of prior learning protocols. In retrospect, dedicated project management resources would have reduced administrative burden and improved implementation.

Students expressed concerns about not having examples of previous work to demonstrate performance expectations during initial unit implementations. UTS responded through scaffolded assessment design incorporating formative feedback on drafts, and by making explicit connections to authentic workplace situations.

Embedding sustainable change through governance frameworks

UTS implemented change management through curriculum governance. The core teaching team meets fortnightly to maintain programme coherence and address emerging issues. The shared sessional teaching team model, described above, allows the same staff to teach across multiple units, supported by professional development sessions focused on core units. This deepens staff's understanding of how units support each other. Student communication strategies (including information portals, detailed unit descriptions, regular announcements) reinforce how units relate to each other.

Example 6. USYD: Introducing the Professional Engagement Programme

Identifying the need for change

The Professional Engagement Programme (PEP) was introduced in 2018 for commencing students in undergraduate engineering degrees — around 900

students. Previously, many students had been unable to obtain a suitable internship and hence to meet their professional practice requirements, and so were unable to graduate. The introduction of PEP meant that students were able to meet this requirement through other forms of exposure to professional practice beyond just internships.

Programme design

A new programme was designed engaging students in professional practice from entry to graduation. Each student completed online modules and attended one 2-hour face-to-face workshop each semester, completed a minimum number of professional engagement activities, and documented and reflected on these. Workshops included researching skills required by employers, preparing CVs, interview practice and self-evaluation of technical and non-technical skills. One of the main outcomes of the programme was to make explicit the transferable skills required by professionals.

Stakeholder engagement strategy and managing multisource resistance

Individual meetings with coordinators defined activities students could claim as 'professional engagement'. Claimable activities included industry projects, site visits, guest lectures, and industry practice training. However, the availability of these varied across units. Students who found themselves in units without such activities were left to source their own engagement hours, prompting frustration. Over time, academics responded to pressure by incorporating opportunities into units lacking these activities.

Student resistance initially focused on the question why they had to complete this extra work when previous students had not had to (prior to the introduction of PEP students were required to complete a 12-week industry placement rather than the now compulsory PEP activities). Resistance required careful management at all levels. Students realised the benefits as they progressed into their fourth year and found it easier to obtain work placements.

Demonstrable results

From 2018, no student has been unable to graduate due to a lack of work experience. However, there were still students who disapproved — these were mainly well-connected students who would have secured work experience without difficulty under the previous system. A partnership programme with student societies to credit professional engagement activities was generally welcomed by participating students. The backlog of students from before 2018 were given access to resources from PEP which, with targeted coaching, enabled them to complete outstanding professional practice requirements.

The change management experiences described above provide practical context for the reflections that follow. We examine the enablers, ongoing challenges, and lessons these programmes offer engineering educators considering similar reforms.

5 Review and future outlook

USYD and UTS have integrated transferable competencies and skills within large-cohort engineering programmes. This required sustained institutional commitment, continuous adaptation, and a willingness to learn from both successes and setbacks.

We identified a range of critical enablers that proved essential for both institutions. These enablers cluster around three interdependent domains: leadership and governance, people and coordination, and external validation supported by evidence. You can use these to assess your institution's readiness, prioritise investment, and anticipate implementation risks.

5.1 Key enablers: leadership and governance

Strong leadership and support structures emerged as enablers for integrating transferable competencies and skills. Sustained advocacy from senior leadership was essential for navigating institutional complexity, securing resources, and maintaining momentum through leadership changes and budget cycles. Formal governance structures provided continuity beyond individual champions and supported alignment with accreditation and institutional strategy.

We observed effective leadership and governance in the second evolution of both programmes. Rather than being abandoned or replaced, initial designs were refined, indicating institutional confidence in their value. This evolution reflects a pragmatic philosophy: launch something 'good enough to begin' and then refine it through evidence-informed review, allowing quality assurance and continuous improvement to coexist.

5.2 Key enablers: people and coordination

Large-scale implementation amplifies coordination demands, making team growth and sustained coordination central to success. Both institutions required dedicated teaching teams, shared curriculum artefacts, and ongoing collaboration to maintain coherence. Team development requires recruiting staff with disciplinary expertise and commitment to curriculum innovation. This is critical for maintaining consistency and quality.

Evidence of effective coordination includes a cultural shift in institutional language and staff confidence. Over time, transferable competencies and skills moved from experimental initiatives to established practice. Staff increasingly referenced shared frameworks from other units and contributed to ongoing refinement. We identified resource recognition as an ongoing challenge: coordination, induction, and alignment require permanent resourcing rather than reliance on goodwill or periodic curriculum reviews. These observations are drawn from experience rather than formal survey data. Systematic evaluation of staff engagement represents an area for future

investigation and could provide valuable evidence for institutions seeking to build the case for similar reforms.

5.3 Key enablers: external validation and evidence

External validation from accreditation requirements and industry advisory boards shifted internal discussions from whether transferable competencies and skills should be integrated to how best to optimise them.

Evidence of successful entrenchment includes growing student acceptance over time. While initial resistance recurred with each cohort, student perceptions shifted as learners progressed through the degree and experienced the relevance of transferable competencies and skills in industry engagement.

5.4 Key success factors

Three strategic approaches were crucial for long-term success.

Progressive scaffolding with clear curriculum mapping proved more effective than isolated skill development. We found that systematically building competencies from foundational to advanced levels, while reducing support as students progressed, better prepared graduates for professional practice.

Authenticity matters because students learn the interdependence of professional and technical competencies only when they must apply both together.

Continuous improvement rather than a 'set-and-forget' approach was required for sustainable implementation, requiring ongoing refinement based on evidence and feedback. Continuous improvement was embedded in programme governance rather than occurring only during periodic reviews.

5.5 Challenges and ongoing issues

Despite these successes, we continue to grapple with persistent challenges.

Resource allocation creates ongoing tension. Coordination across large cohorts requires significant time but lacks recognition. At substantially larger scales, specific elements may encounter bottlenecks; e.g., shared tutor models become harder to sustain, and assessment consistency demands additional quality assurance. If you are operating at greater scale, you should anticipate that governance and resourcing need to expand proportionally, with dedicated programme management roles rather than reliance on academic goodwill.

Staff turnover and training present ongoing challenges. New academic staff require systematic induction to understand our distinctive approach. Maintaining programme coherence across changing teaching teams demands systematic knowledge transfer.

Student resistance resurfaces with each cohort. Despite programme success, every intake includes sceptics, requiring renewed justification. While resistance diminishes as students progress, managing initial scepticism remains resource intensive. Presenting students with evidence that recent graduates identify their professional

rather than technical skills as underdeveloped upon entering practice (Lowe et al., 2026) may help to address this resistance.

Assessment validity remains an ongoing challenge. Capturing meaningful evidence of integrated competency development, without overburdening students or staff, demands continuous refinement.

5.6 Recommendations for engineering educators

For institutions considering similar approaches, we suggest the following:

Vision and governance

Start with a clear vision. You should develop a compelling narrative about why transferable competencies and skills enhance technical excellence. Structure follows purpose.

Build governance, not just programmes. If you want curriculum integrity to endure, you must establish permanent governance structures. Curriculum integrity demands sustained attention. Dedicate resources to prevent alignment drift through regular monitoring and coordination.

Leverage external validation. Use industry advisory boards and professional accreditation requirements to build support and validate approaches.

Design and assessment

Map systematically. You should be able to identify clearly where competencies are introduced, practised, and mastered across the degree.

Design for authenticity within constraints. Integrate competency development within real-world contexts that are relevant and maintain appropriate scaffolding for learning.

Change management

Invest in change management. To survive long-term, you need to implement resources and management strategies properly. Prepare evidence-based responses to predictable resistance. Acknowledge constraints when explaining difficult decisions. Equip front-line staff to deliver consistent messages — they shape student perceptions.

Embrace iterative improvement. You will not get everything right the first time. Establish mechanisms for gathering feedback and refining the programme systematically. Compressed timelines often necessitate pragmatic decision making; continuous refinement represents essential practice.

Develop stamina and resilience. Implementing comprehensive change requires patience, persistence, and thick skin. Expect criticism, prepare evidence-based responses, and maintain a long-term perspective.

Our experience demonstrates that, while challenging, comprehensive transferable competency and skill programmes can become embedded institutional practice within large, diverse engineering cohorts. Success requires patience, flexibility, and ongoing

institutional commitment to continuous improvement and evidence-based refinement. If you are undertaking similar reform, recognise that this work demands sustained effort and resources — it is an ongoing commitment to educational excellence.

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4.10

Engineering Innovation and Leadership at The University of Texas at El Paso

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The BSc in Engineering Innovation and Leadership (E-Lead) at The University of Texas at El Paso (UTEP) is an ABET-accredited engineering degree that is transforming how engineering is learned and taught. At its core, E-Lead is an integrated engineering degree that provides students with a diverse foundation in multidisciplinary engineering knowledge, leadership theory and practice, innovation skills, and an understanding of business. The degree is customisable, allowing students to couple their E-Lead education modules with a focus on a specific traditional engineering discipline. This content knowledge is then integrated and applied through the E-Lead core modules each semester, enhanced by peer and faculty support and extracurricular programming offered by the department. As an undergraduate degree, team-based, project-based learning is the cornerstone of how we support our students in developing transferable competencies and skills. This project work is facilitated in our dedicated studio space, where students not only attend class but can collaborate on campus after hours and use the available prototyping lab to work on their projects. Therefore, the E-Lead degree focuses on developing a learning environment where transferable skills flourish, using real-life scenarios and projects to prepare students to take the initiative to ‘engineer’ the future and solve sociotechnical challenges. The chapter concludes with practice-focused recommendations for designing integrated engineering leadership curricula, including strategies for scaffolding transferable skills, aligning leadership development with technical coursework, and engaging industry partners.

1 Introduction

The BSc in Engineering Innovation and Leadership at UTEP, also known as the E-Lead degree, was established with the overarching purpose of revolutionising engineering education — within the institution, nationally, and internationally. It was designed to address a critical gap identified by employers: while engineers possessed strong technical capabilities, they often lacked essential professional skills. Therefore, a key aim of the degree is to cultivate these skills, including interpersonal interaction, financial literacy, policy understanding, and team leadership, by integrating them within a broader context of engineering studies. This approach moves beyond purely technical instruction to incorporate entrepreneurial skills, enabling students to grasp the broader societal and economic implications of their engineering work. We say that we have created a degree that is ‘more than engineering’.

The degree was a direct response to pressures from both industry and the engineering education community, aiming to create a new educational model that provides practical experience, rather than focusing solely on theoretical and technical concepts. The vision for E-Lead is to foster the holistic development of students, enabling them to think comprehensively about problems and their impacts. It emphasises the cultivation of engineering leaders through a curriculum heavily reliant on meaningful, team-based, real-world projects spanning all years of the degree. These projects serve as crucial vehicles for developing a diverse range of skills, including leadership. Conceived as an agile ‘tugboat’, the degree is a flexible model that can influence and lead the entire engineering college towards adopting innovative teaching methodologies, adapting as needed to evolving educational and industry demands.

To further articulate how E-Lead seeks to achieve this integrated learning for our students, we seek to share the philosophy and approach to developing the degree by establishing institutional context, describing conceptual and theoretical underpinnings of our curricular design and improvement, and identifying future directions for growth. In this chapter, *competencies* refer to the integrated combinations of knowledge, skills, and attitudes, while *transferable skills* describe capabilities applicable across engineering contexts, such as teamwork, communication, and ethical reasoning. In some literature, professional skills are broadly termed ‘leadership’ (Duderstadt, 2008). Therefore, in this chapter, leadership is defined not as a positional role, but as a set of transferable engineering competencies that enable individuals and teams to design, collaborate, and act responsibly within these complex sociotechnical systems. This interpretation aligns with the SEFI skills framework (SEFI, 2025) and the European Qualifications Framework’s emphasis on autonomy, responsibility, and professional competence. This chapter is also structured to align with the handbook by first defining leadership competencies, then describing curriculum design and implementation and finally offering recommendations for adaptation and other institutional contexts.

2 Institutional context and need

The University of Texas at El Paso (UTEP) is an open-access, Hispanic-serving institution located on the United States-Mexico border, where approximately 84% of

the student population is Hispanic, more than half are the first in their family to go to college, and approximately 47% are from the lowest income quartile. Thus, UTEP contributes to the upward social mobility of its graduates. Of the nearly 25,000 students, approximately 5,000 are pursuing engineering degrees. As an open-access institution, all students with a high school diploma or equivalent are accepted. Additionally, regardless of their academic preparation, students are accepted to any major of their choosing at UTEP, presenting unique challenges especially within the College of Engineering. Students therefore begin their engineering degrees with varying levels of preparation. As E-Lead serves students who have historically been underserved by higher education, cultural and economic considerations were key in designing the E-Lead degree.

The institutional context for the E-Lead degree began with the arrival of a new dean, the administrative head of all faculty and departments, at UTEP in July 2007, who, in their first dean assignment, was exposed to national discussions on engineering education reform at a nationally sponsored conference. This experience, particularly through reports like Duderstadt's (2010) *Engineering for a changing world*, provided a crucial understanding of the broader need for change. Internally, the E-Lead degree was envisioned as a catalyst within the larger Engineering college, capable of leading and influencing curriculum changes across traditional departmental structures and indicating an institutional willingness to innovate. Furthermore, internal discussions had already generated momentum for an engineering leadership programme, suggesting a receptive environment within UTEP for such an initiative. The need for the E-Lead degree was multifaceted, driven primarily by a long-standing national imperative for fundamental changes in engineering education in what is taught and how. A significant factor was the consistent feedback from industry partners that while engineering graduates were technically proficient, they lacked essential professional skills, encompassing abilities in human interaction, financial understanding, policy navigation, and team leadership. The degree was thus a direct response to this industry demand for more well-rounded engineers.

This led to the desire for a new educational model, one that would mirror professional fields like medicine by providing practical, real-world experience through rotations and hands-on projects, moving away from purely theoretical classroom learning. Beyond immediate educational needs, the E-Lead degree was seen as essential for contributing to the innovation engine for the US and addressing major issues that are facing humankind in general, with the belief that UTEP graduates would play a crucial role in tackling complex societal challenges. This vision extended to the idea of engineering becoming the liberal arts degree of the 21st century, suggesting a future need for broader access to engineering principles and a model for integrating engineering into wider curricula, including primary and secondary education, due to the increasing need for technical skills across diverse fields.

3 Competencies and skills development

In E-Lead, we define transferable skills in engineering as those professional and interpersonal capabilities and competencies beyond strict technical expertise that are

crucial to an engineer's success and adaptability in diverse professional settings. They are the skills in demand by the employers of our students but are often neglected in traditional technically focused training. These transferable skills are seen as essential for engineers to drive innovation for the US and address major issues that mankind is facing, implying that complex global challenges necessitate leadership and a broad skillset. Their acquisition is fundamental for accelerating career advancement into leadership roles and for adapting to an ever-changing professional landscape, supporting the idea that engineering education, with its blend of technical and transferable skills, making engineers versatile across numerous fields. Finally, early student exposure to such teamwork and interaction facilitates the forging of relationships and the creation of support structures, contributing significantly to students' personal and professional growth. These skills are vital for fostering the holistic development of engineers, transforming them into well-rounded professionals capable of understanding and contributing to the wider implications of their work.

In reviewing the goals of our programme with students and practicing engineers, we realised that the specific transferable skills that were most valued could be encompassed in the concept of engineering leadership — including effective interpersonal interaction, financial understanding, policy navigation, team leadership, and problem-solving within a broader context. Furthermore, unlike how most of our engineers are trained in a classroom setting, engineering work includes robust teamwork and collaboration abilities, recognising that engineers rarely work in isolation and must foster trust and communication within teams. Business acumen, involving a grasp of financial concepts and business models, is also a key component. Therefore, we use the definition of an engineering leader as one who will: *"(a) employ the full range of engineering skills and knowledge in the design of sociotechnical innovations, while (b) seeking to understand, embrace, and address the current and future impact of their work in context by (c) actively fostering engaged and productive relationships with diverse stakeholders, including themselves and their team, the users of their technologies, and those impacted by their engineering work"* (Kendall et al., 2022, p. 17).

3.1 Leadership development

Leadership development in the E-Lead degree is systematically scaffolded through a progressive and deeply integrated approach, focusing on hands-on, team-based projects that grow in complexity and scope throughout the entire curriculum. This foundational aspect means that leadership skills are not isolated within a single module, but are continuously developed from the first year onwards, providing ongoing exposure to knowledge, skills, and mindsets necessary to foster engineering leadership. This development is seamlessly intertwined with technical learning and the acquisition of business acumen, ensuring that students apply leadership principles directly to engineering problem solving. This requires students to consider the financial and societal impacts of their engineering work. This integrated method solidifies leadership as an essential facet of engineering practice, rather than an add-on.

The consistent focus on project work follows a natural progression, with projects becoming increasingly complex and relevant to real-world applications. This progression allows for a systematic scaffolding of leadership abilities, advancing from basic teamwork and communication to more sophisticated team management, complex problem solving, and decision making. Furthermore, students are trained to adopt a holistic problem-solving mindset, encouraging them to think broadly about challenges and their wider implications, thus fostering a comprehensive leadership approach. Early in the degree, a strong emphasis on teamwork and interpersonal interaction helps students forge relationships and build a crucial support structure by setting expectations and preparing them for a collaborative professional environment. By the end of the degree, E-Lead intentionally connects students with companies to work on a capstone design project, reinforcing the practical application of these scaffolded skills and preparing graduates for real-world leadership roles.

3.2 Theoretical framing

This chapter adopts the Contextual Engineering Leadership Development (CELD) framework (Campos Valles et al., 2025; Kendall et al., 2018; see also Chapter 2.5 in this handbook) to provide conceptual clarity around how leadership is defined, developed, and scaffolded within the E-Lead degree. CELD frames engineering leadership as a developmental and contextual process that is inseparable from technical work, rather than a generic or positional skill set. Within this framework, leadership development progresses across three interrelated domains: effectual behaviour at the individual level (e.g., identity, motivation, reflection, and initiative), collaboration at the team level (e.g., communication, coordination, and shared problem solving), and contextual awareness at the societal level (e.g., ethical reasoning, stakeholder engagement, and social and economic impacts of engineering work). This framing aligns with E-Lead's curriculum-level scaffolding, in which students encounter increasingly complex engineering projects that require simultaneous growth in technical competence, teamwork, and sociotechnical judgement over time, rather than isolated leadership instruction.

Complementing CELD, intrinsic motivation and self-directed learning (SDL) serve as the philosophical underpinnings of how learning is designed to occur within the E-Lead degree. Drawing on problem-based learning literature, SDL is understood as both a learner capability and a deliberate design feature of the curriculum, wherein students — supported through structured projects, facilitation, and reflection — progressively assume responsibility for defining their own learning needs, identifying and evaluating resources, and assessing their own learning (Loyens et al., 2008). Intrinsic motivation is fostered through meaningful, authentic engineering problems and autonomy-supporting learning environments, particularly within the cohort-based studio model used in E-Lead. Importantly, SDL in this context does not imply unguided or independent learning; rather, it reflects scaffolded autonomy, ensuring that students with diverse levels of preparation are supported as they develop the capacity to 'learn how to learn' and to enact leadership within engineering practice.

3.3 Change management

When communicating our approach to leadership development to students and fostering their own motivation to grow as leaders, we apply a concise framing that we call the 'three Cs' of E-Lead. The three Cs, adapted from the leadership development framework used at the United States Military Academy at West Point (Donnithorne, 2009), are foundational pillars that describe the aspects of leadership we focus on. The pillars focus on students' adaptability to change and growth throughout their E-Lead experience. The pillars include:

- *Character (who you are)*. This pillar emphasizes personal integrity, self-awareness, and ethical grounding. Students are encouraged to reflect on their values, motivations, and identity as future leaders. The goal is to cultivate individuals who lead with authenticity and purpose.
- *Competence (what you know)*. Competence refers to the technical knowledge and intellectual foundation required to lead effectively in engineering contexts. The E-Lead curriculum integrates rigorous engineering coursework with leadership theory and business acumen to ensure students are well-prepared for complex problem solving and decision making.
- *Capacity (how you catalyse change)*. This pillar focuses on the ability to apply knowledge and character in real-world settings. It includes skills like collaboration, innovation, and initiative. Students develop the capacity to lead teams, manage projects, and drive change in diverse environments.

These three pillars are central to UTEP's vision of producing 'Renaissance engineers' who are holistically educated and capable of leading in a variety of contexts.

4 Curriculum design

4.1 Philosophy and design

To foster an intrinsically motivating learning environment, a central design element in E-Lead is the pervasive reliance on meaningful, team-based, real-world projects integrated throughout all four years, serving as the primary vehicle for acquiring both technical content and transferable skills. The scaffolded nature of the curriculum and the project focus foster students' development of intrinsic motivation by giving them opportunities to develop their competence, sense of belonging, and autonomy (Loyens et al., 2008).

To ensure that students see the connection across the levels of impact in the CELD, the curriculum is intentionally integrated, blending technical coursework with lessons on leadership, business acumen, and communication, ensuring skills are applied within real engineering challenges. This design explicitly cultivates a range of essential transferable skills, including leadership, teamwork, communication, innovation, and business understanding, vital for employability and adaptability. Furthermore, the design incorporates robust industry collaborations to provide authentic projects and ensure curriculum relevance to employer needs, with companies specifically seeking out E-Lead students for their leadership potential. Finally, the degree's design encourages students to analyse the comprehensive upstream and downstream impact

of their solutions, fostering a broad understanding of their work's effects, and maintains an iterative and adaptive approach, allowing the degree to evolve based on experience and feedback.

4.2 Curriculum and implementation

The E-Lead degree is designed with a strong emphasis on integrating business, leadership, and design throughout all years, primarily achieved through extensive project-based learning. Real-world, team-based projects are central to the curriculum from the first year, serving as the main vehicle for intertwining technical engineering challenges with leadership development and an understanding of business implications. This comprehensive integration extends to business acumen modules that evolve from personal finance to broader business understandings by the fourth year.

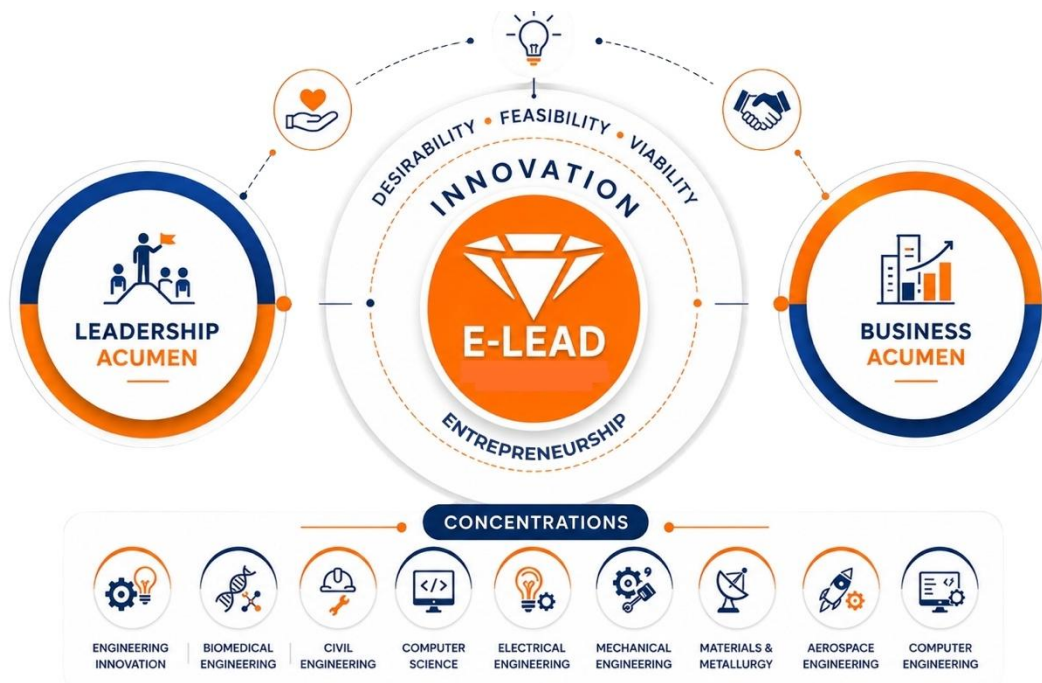


Figure 4.10.1: Illustration of E-Lead structure developed by the Engineering Education and Leadership department at UTEP. Copyright UTEP 2026, used with permission, no further use allowed.

Because this programme is housed in a college of engineering at an established university and accredited as a general engineering programme, the degree was designed to make use of existing coursework and satisfy university and accreditation requirements, while maintaining a coherent thread of modules to tie the material together. Therefore, every student completes a required university core that covers basic science, mathematics, and the humanities. Each student selects one of nine engineering concentrations, corresponding to a range of engineering disciplines; each concentration consists of a prescribed set of modules offered by the disciplinary

department (Fig. 4.10.1). The content of the university core and engineering concentration modules is integrated with leadership, business, and innovation in the eight E-Lead modules and two professional practice modules. Depending on the student's selected engineering concentration, they may also have additional emphasis or elective modules that they can select to help round out their knowledge and skills in alignment with their career goals and complete their degree requirements.

In the E-Lead core modules (Table 4.10.1), we scaffold intentional content and skill development throughout the required coursework. In the first year, incoming students focus on acclimating to university life and the E-Lead environment while building a community and gaining foundational design, mathematics, and communication skills. Leadership development emphasizes building emotional intelligence and leading themselves with accountability to peers and instructors. This focus corresponds to the development of self and effectual behaviour at the centre of CELD. In the second year, as students move from a focus on individual to team leadership development in CELD, students begin to experience the power of engineering to impact the world by using the engineering modelling process to explain, predict, or otherwise manipulate the behaviour of systems around them. Through the modules in the second year, students begin working more explicitly on teamworking skills as they generate models, design experiments, and validate their assumptions about the engineered world. In the third year, students expand on the modelling and measurement skills that they have developed to consider the impact of the technology they design on users and social systems. This is the beginning of the shift from focusing on teaming and beginning to move toward tangible impact in their community and society through understanding the context of their engineering work; the final circle of CELD. This is accomplished using two lenses: first, a user-centred design project focused on the needs of an individual client, and second, a lean startup engineering entrepreneurship project focused on the needs of a broader customer segment. Consequently, teams are learning and practicing key engineering leadership skills of vision creation, conflict resolution, and project management. They are also being explicitly introduced to business concepts, including finance, accounting, and marketing, as they consider a viable business model for their engineering startup.

In the final year, students complete a year-long capstone experience. In their capstone projects, students apply their integrated knowledge and skills that have been developed across all previous years in the curriculum. A defining element of the capstone experience is connection to industry through projects that are sourced from industry partners. This focus on industry-driven projects ensures that students develop skills directly relevant to employer needs and prepares them for the transition into their careers. The degree aims to develop engineers who are technically capable while also possessing the other professional skills that are necessary for immediate professional contribution. The scaffolded structure of the degree with corresponding CELD integration is further illustrated in Fig. 4.10.2.

Table 4.10.1: List of E-Lead-specific modules across the curriculum (UTEP, n.d.)

<i>Year and primary CELD emphasis</i>	<i>Autumn module</i>	<i>Spring module</i>
	Engineering innovation and leadership	Fundamentals of leadership, design and graphics
<i>Year 1: Effectual behaviours at the individual level</i>	Through this module, students will gain engineering foundational knowledge of innovation, technological, and leadership advancement in modern society, develop principles of personal, professional, and social responsibility for living in a diverse world, and intellectual and practical skills that are essential for all learning.	This module equips students with fundamental skills to help thrive during the pursuit of their BSc in Engineering Innovation and Leadership. Therefore, a major focus of the module is to help students develop their own identity as leaders and as engineers. Another focus of the module is to build community and culture within the programme. Further, this module introduces students to the flipped classroom and project-based learning styles common in E-Lead modules. The final focus of this module is the development of critical engineering graphics skills for students.
	Modelling and simulation	Engineering measurements
<i>Year 2: Teaming</i>	This module introduces the use of difference and differential equations in the modelling of systems with examples drawn from the life and natural sciences, engineering, and business. Computer simulations are developed using programming in Python. Topics also include leadership theories and practices.	In this module, students learn some of the basic tools for making physical measurements and conducting experiments with electric circuits. Topics include the fundamental laws that govern the operation of electric circuits, along with formal techniques associated with the analysis and design of electric circuits. Professional communication skills are developed via formal laboratory reporting. Readings on leadership character and integrity are included.

<i>Year and primary CELD emphasis</i>	<i>Autumn module</i>	<i>Spring module</i>
	People to Products	Products to People
<i>Year 3: Teaming & community /society</i>	This module covers all basic concepts of systems engineering. The objective is to provide the basic knowledge and tools for transforming an operational need into a well-defined system configuration, through an iterative design process of issue formulation, analysis, optimization, design synthesis, system integration, and testing.	This module is the second in a two-module sequence on developing innovative start-ups. It is intended to give students an opportunity to experience the human-centred commercialization process from start to finish in a single semester. In teams, students will move from a functional prototype to a business model that prepares them for a go/no-go decision. It requires students to conduct empirical experimental through interviews with people in their start-up's ecosystem, to recognize the impacts of the start-up on the ecosystem, and to function effectively on teams.
	Capstone design 1: Definition and exploration	Capstone design 2: Develop and evaluation
<i>Year 4 : Contextual awareness and bringing it all together</i>	This module is the first semester of a two-semester capstone module in Engineering Innovation and Leadership. The module particularly focuses on preparing and implementing a project design. Engineering innovation and leadership skills are applied to build a cohesive team and to successfully execute a real-world project.	This module is the second semester of a two-semester capstone module. Engineering innovation and leadership skills are applied to execute a successful real-world project.

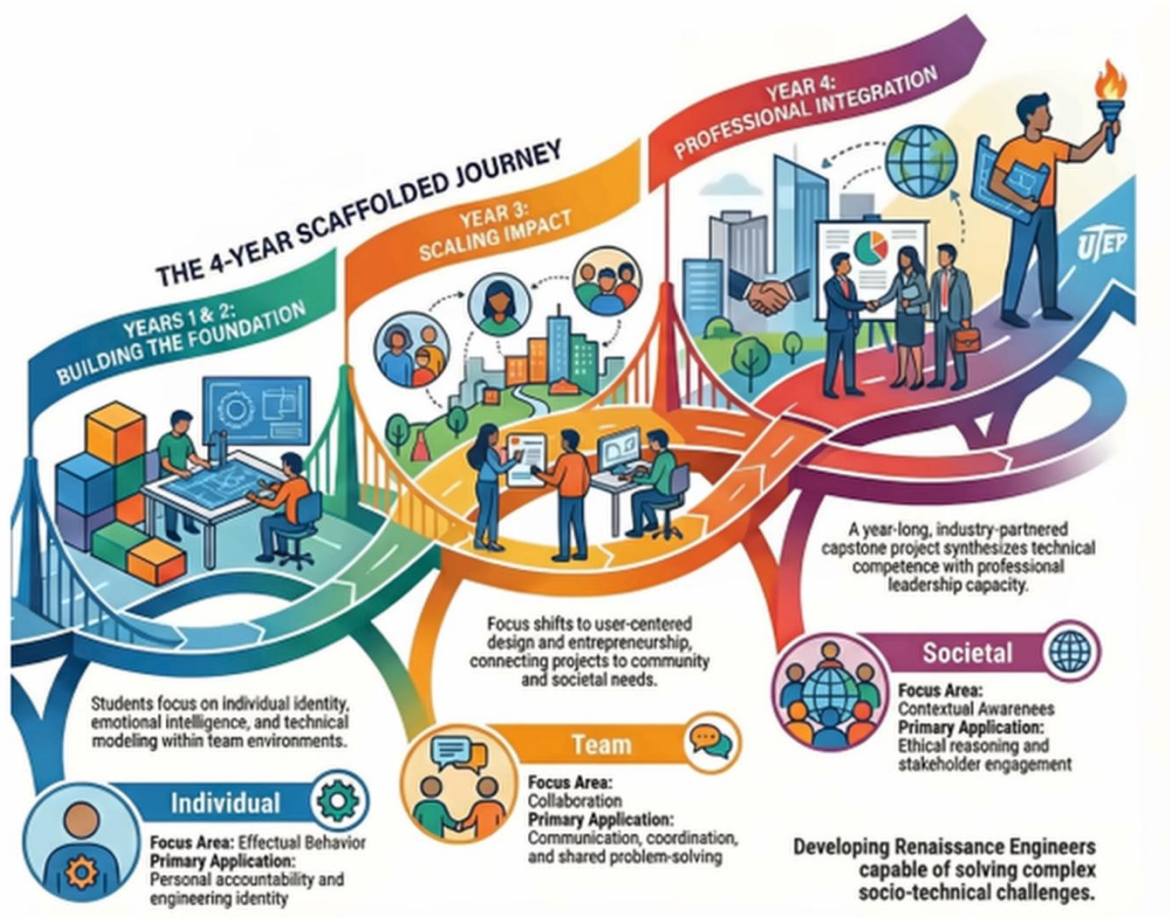


Figure 4.10.2: Illustration of the four-year scaffolded journey with CELD integration developed by the Engineering Education and Leadership department at UTEP. Copyright UTEP 2026, used with permission, no further use allowed.

Finally, the degree includes professional practice requirements, which highlight the consistent emphasis on real-world application and industry relevance, particularly in later years. Students are required to complete two 320-hour summer professional practice experiences, the equivalent of a full-time internship during the summer or working part-time during the school year. These can include internships, co-operative learning experiences, other work experiences, research, or teaching experiences. These experiences allow students to reflect on and apply skills gained in the E-Lead programme, such as leadership, engineering, business, etc.

Example 1. People to Products module project

In the third year of the E-Lead curriculum, students complete a user-centred design project in the People to Products module that emphasizes teamwork and community engagement while developing contextual awareness of engineering practice. This project also provides students with ample opportunities to exercise their own effectual behaviours while managing schedules, navigating conflict, and communicating with stakeholders. Teams partner with a local non-profit; currently

the module educators maintain a partnership with an organization that provides early intervention services to children under the age of three with developmental delays. For this collaboration, students design adaptive products tailored to the needs of individual client families. Students work in teams of four or five that are assigned based on best practices for teamwork, such as avoiding isolation of underrepresented demographics and considering schedule alignment. The students follow a human-centred design process that includes understanding client needs, generating and refining design concepts, building functional prototypes, and validating designs through user interaction and testing. Teams were required to meet multiple times with both an assigned mentor from the partner organization and their client family, integrating their stakeholders' feedback throughout the semester as their designs evolved. The culminating experience is an on-campus event during which teams deliver their products to the client families and present their work to the client families, partner organization staff, programme educators, and peers, emphasizing both technical justification and responsiveness to user needs.

Assessment in the project is intentionally multimodal and aligned with the module's dual emphasis on engineering design competence and contextual awareness. Staff assess student work across the semester using structured rubrics applied to intermediate and final deliverables, including design definition artifacts, prototypes, and testing reports. Technical assessment focuses on the appropriateness of the proposed solution, use of an explicit engineering design process, and product quality, with particular attention to how teams translate user needs into quantified design specifications and validate performance through modelling and testing. User-based assessment is conducted during the final event using a dedicated client rubric, which evaluates the teams' demonstrated understanding of the child and family needs, the relevance of the proposed solution, product quality based on observed use and feedback, and the effectiveness of communication during the presentation.

Example 2. Capstone module sequence

The two-semester, industry-partnered capstone design project integrates technical knowledge, leadership development, and contextual awareness. A typical project is sponsored by an external industry or community organization and framed around an authentic, open-ended engineering design problem with economic and operational constraints. Teams of three to five students work with a dedicated industry mentor with supervision by module educators to define the problem, explore design alternatives, and develop and evaluate a feasible solution over the academic year. Teams are self-organizing; students commonly assume functional roles such as technical lead and documentation lead. The only required role is the project manager, who is nominated by a team-directed process and approved by the module staff. This structure supports students in practicing effectual behaviours at the individual level — such as initiative, self-awareness, and reflection — while

coordinating technical and interpersonal work within the team and engaging with external stakeholders whose needs and constraints shape the design context.

The capstone module sequence intentionally targets leadership development across the CELD domains. Individually, students are required to reflect on their learning and leadership growth through structured written reflections. At the team level, students develop collaboration, communication, and project management skills by negotiating roles, managing conflict, and aligning technical decisions with shared goals and timelines. At the societal level, teams are expected to consider the broader impacts of their designs, including ethical responsibilities, economic feasibility, and downstream effects on users and partner organizations.

Assessment includes evaluation of technical deliverables (e.g., design reports, prototypes, validation results), peer and self-assessment of teamwork and leadership behaviours, and feedback from industry mentors. Together, these assessment methods reinforce the capstone as a culminating experience that synthesizes technical competence, leadership capacity, and contextual judgement, preparing students for professional engineering practice beyond graduation.'

4.3 Impact and outcomes

Alumni from the past decade have provided positive feedback about E-Lead and offered suggestions for improvement through a combination of focus groups and surveys.

Programme strengths

Alumni were enthusiastic about several aspects of the E-Lead programme. They highly valued the strong community and peer relationships fostered by the programme, which they consider a significant benefit. The curriculum's focus on critical thinking, metacognition, and adaptability was also consistently praised. Alumni felt these skills prepared them to navigate complex and ambiguous professional situations. They also highlighted the value of tangible resources, such as access to professors, internships, and professional practice opportunities.

Areas for improvement

While the feedback was largely positive, several areas for improvement were identified. The most prominent concern was the programme's marketing and branding. Alumni noted that the name Engineering Innovation and Leadership is confusing and hinders recruitment and career prospects, particularly with recruiters who don't understand the programme's unique value proposition. This lack of clarity also extends to the programme's structure, where the flexibility and autonomy, while appreciated, can lead to confusion and a lack of clear career guidance, especially for international students. Some alumni also debated whether the programme should incorporate more technical skills, such as programming. The second year of the programme, in which students develop their programming and circuits skills, and the need for more structured career support were also highlighted as areas needing

review. This stage is pivotal because students are expected to consolidate foundational technical knowledge while beginning to make more informed decisions about their engineering discipline, professional identity, and longer-term career pathway.

Proposed initiatives and actions

To address these issues, alumni proposed several changes. They suggested integrating practical activities like mock interviews into the curriculum to help students better articulate their skills to employers. They also called for a more streamlined degree plan that balances flexibility with clearer guidance. To improve career outcomes, they suggested more dedicated support, including alumni talks and mentorship programmes to help students explore different career paths. The most significant proposal, and one that was divided among alumni, was changing the programme's name to reflect its value better and improve external perception. At the time of writing, there are ongoing conversations about a name change; however, no action has been taken. Other ideas included celebrating student achievements and providing more in-depth education on personal finance and project management across all years in E-Lead.

5 Conclusion

5.1 Lessons learned and recommendations

The E-Lead degree has yielded substantial impacts and outcomes, significantly shaping its engineering graduates and influencing the broader educational landscape. A key outcome for students is the cultivation of well-rounded engineers who not only possess strong technical competence, but also crucial professional skills previously identified as lacking by employers, including improved interpersonal skills, financial understanding, and team leadership. Furthermore, students develop enhanced problem-solving capabilities, learning to think broadly about issues and their immediate and long-term impact, which equips them for complex real-world challenges extending beyond purely technical solutions. The degree's strong emphasis on team-based projects from the outset leads to improved teamwork and collaboration, helping students forge relationships and build robust support structures. This emphasis also contributes to an increased leadership potential, as companies are actively drawn to E-Lead students, recognizing their capacity for leadership in rotational programmes and various industry roles. Ultimately, the practical and project-oriented nature of the degree ensures graduates are highly adaptable to industry needs, making them well-prepared for professional practice with skills directly relevant to employer demands.

Beyond individual student impacts, the E-Lead degree has made significant contributions to engineering education and beyond. It was created with the overarching goal to change what and how engineering is taught nationally, and by pioneering a new model, it aims to contribute to broader reform across engineering education, resulting in UTEP spearheading the Alliance for Integrated Engineering (A4IE), which offers a mechanism for sharing lessons learned, supporting emerging programmes at other public universities. This has positioned E-Lead as a leader within

a broader national conversation about integrated engineering education. The degree functions as a flexible and adaptive model for educational innovation within the engineering college, successfully demonstrating alternative pedagogical approaches. The degree also effectively bridges the gap between academic theory and industry practice through its integration of real-world projects and strong industry connections, ensuring graduates are workforce-ready. More broadly, the degree's ambitious vision is to contribute to national and global innovation and address major societal issues speaking to its long-term societal impact through its graduates, an ongoing challenge. Finally, it contributes to redefining the role of engineering, promoting the perspective that engineering is seen as a foundational skill set needed across many different areas, potentially leading to a wider integration of engineering principles in education.

In terms of recommendations, at the programme level, senior leaders and programme teams play a key role in creating conditions that support meaningful student learning and development. Effective implementation depends on both top-down and bottom-up commitment, supported by the identification of programme champions who can advocate for and sustain the initiative across the institution. Establishing and clearly communicating a shared programme culture is essential for aligning values, expectations, and pedagogical approaches among academic staff and professional services. Processes for monitoring and review should be embedded within existing quality assurance and enhancement structures, with a clear emphasis on ongoing enhancement rather than compliance-driven evaluation. Continued engagement with industry practitioners and alumni networks is also critical, ensuring that curricula remain relevant, informed by professional practice, and responsive to the expectations of employers and professional bodies.

At the module and classroom level, lecturers and teaching staff are central to enacting programme-level aims through curriculum design and pedagogy. Teaching approaches should intentionally incorporate opportunities for reflection, enabling students to consolidate learning and develop a sense of progression across their degree programme. Autonomy and choice should be offered in ways that are appropriately scaffolded across levels of study, supporting students' increasing independence as learners. The development of transferable and professional skills should be embedded within engineering contexts and aligned with technical learning outcomes, rather than positioned as separate activities. Finally, teaching should be responsive to students' prior attainment and educational backgrounds, with adjustments to analytical depth and learning expectations that recognise variation in mathematics and science preparation, including those entering via alternative routes.

5.2 Future directions

Looking ahead, E-Lead is focused on refining its identity, strengthening its curricular coherence, and clarifying the pathways students use to connect their integrated engineering preparation with future careers. A near-term priority is to examine how the programme communicates its purpose and value to students, families, employers, and university partners, including whether its current name adequately conveys the technical, leadership, and innovation competencies students develop. This work is

closely connected to ongoing review of the degree plan, particularly the second year, where students build foundational programming and circuits skills while beginning to make more consequential decisions about their engineering discipline and professional direction.

Future development will also require more structured career support, including earlier opportunities for students to practise articulating their skills, connect with alumni, understand the range of career pathways available to integrated engineering graduates, and translate project-based experiences into language recognised by employers. At the programme level, E-Lead is likely to continue expanding partnerships with industry and community organisations so that projects remain authentic, technically meaningful, and responsive to emerging workforce needs. E-Lead's next phase is not simply about sustaining an existing model, but about sharpening the programme's identity, improving student navigation through the curriculum, and extending its influence through collaborative programme development.

5.3 Resources and further reading

Finally, in addition to the literature cited in this chapter, we recommend the following resources if you would like to know more about UTEP and its leadership programme: Gonzalez (2025), Joslyn (2022) and Kendall et al. (2018).

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AI statement

During the preparation of this work, the authors used Microsoft Copilot in order to transcribe and summarize group conversations with each author to frame the content of the chapter and develop an image summarizing the degree structure, as well as to synthesize existing module documentation (syllabi, rubrics, assignment descriptions, etc.) to generate succinct summaries of project descriptions and assessment. The authors also used Notebook LM to develop Fig. 4.10.2. After using these tools, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

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4.11

Authentically Integrating Communication in the Undergraduate Engineering Curriculum within Cornell Duffield College of Engineering

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Keywords: *engineering curriculum, communication skills, curricular agility, technical communication, social cognitive learning theories, self-efficacy*

This chapter outlines the two interlocking frameworks developed within the Engineering Communications Program (ECP) at Cornell Duffield Engineering that guide curriculum, flexible module structure, and authentic integration of communication for engineering purposes: 1) core communicative competencies, and 2) curricular agility. ECP provides the majority of undergraduate engineering communication offerings and supports the accreditation across various degrees in Cornell Duffield Engineering. ECP authentically integrates communication into engineering curricula with sensitivity to disciplinary contexts. To achieve this integration, ECP introduces students to foundational concepts that define communication as contextual, socially situated, purposefully designed, and central to cultivating an engineering identity. Many modules are also partnered with engineering staff, allowing students to engage with not only the technical concepts but also the genres and rhetorical situations characteristic of particular engineering fields. In addition, ECP teaches conventions, genre analysis, problem solving, and working in teams — all of which are much-requested professional competencies. Modules draw on engineering and technology industries, such as approaches to project management and best practices, thus underscoring communication as a professional necessity rather than an auxiliary skill. To empirically ground the efficacy of our framework, ECP provides evidence from longitudinal survey data that shows students develop communicative self-efficacy as a result of engaging in authentic and integrated work. We present this framework as a pedagogical model that situates communication within engineering practice, offering guidance for programmes seeking to prepare students for the communicative demands of professional environments.

1 Introduction: context and history

Communication is irrefutably central to engineering practice, with professional surveys showing that engineers spend a large portion of their time engaged in communicative work (Cunningham & Stewart, 2012; Darling & Dannels, 2003; Kreth, 2000; Sageev & Romanowski, 2001). However, research shows that engineering graduates lack communication proficiency (Brumberger & Ellsworth, 2025; Khoo et al., 2020; Ramadi et al., 2016), with one study recommending further engineering education research on 'learning soft skills in context' (Hirudayaraj et al., 2021). We don't agree with the connotations of 'soft skills', which suggest that communication is easier or secondary to technical work, and we use this chapter to present a pedagogical model for teaching communication as an integral part of engineering practice. Above all, the ECP framework holds that engineers' communicative competence is integral to engineering education, not ancillary.

Prior research shows that engineering staff place high importance on students learning written communication skills, yet they often cite the substantial time it takes to grade written assignments as a barrier (Buswell et al., 2019). This struggle to balance staff and student workloads often results in undergraduates completing engineering communication work with little instruction or pedagogical support (Hutchison et al., 2021). The problem is compounded by the fact that many engineering staff lack training or familiarity with communication theories and pedagogies, which understandably can make them feel hesitant or uncomfortable teaching communication (Brumberger & Ellsworth, 2025; Paretti et al., 2014).

This chapter explores how the Engineering Communications Program (ECP) at Cornell Duffield College of Engineering (New York State, USA) provides unique, flexible communications module offerings, enabling undergraduate students to fulfil their graduation requirements. Module outcomes align with the Accreditation Board for Engineering and Technology's (ABET) student outcomes, which map closely to the European Qualification Framework (EQF) standards (Europass, n.d.)

We begin by describing how our communications programme fits in our institutional context, so that you can consider how your college, department, or programme differs from or aligns with ours. We then outline the theoretical grounding of ECP's approach, which centres on a four-part communications competency framework. In this section, we provide definitions and key sources to help exemplify our theoretical grounding. Next, we describe ECP's curriculum design, including both stand-alone and partner modules. Finally, we share survey data that supports our approach to teaching, learning, and assessment. Our hope is that you will adopt elements of this model to your context and consider using a similar survey to assess the impact of communication instruction on your own engineering students.

1.1 Common engineering communication pedagogy models

We first outline five major pedagogical approaches to teaching communication to engineers (Paretti et al., 2014) but add ECP's model (Evans & Gabriel, 2007) as the one we have found the most productive and agile for designing our engineering

communication curriculum. Pedagogical approaches to teaching communication to engineers vary on whether communication is treated as a general skill transferrable across contexts, a module requirement in a programme, or a situated practice embedded in the work of an engineer. While each model attempts to address the persistent need for communication instruction in engineering programmes, each model also carries limitations and affordances. We believe, however, that ECP's model provides a unique, measurably effective, and replicable structure for teaching engineering students vital communication skills.

Siloed technical writing modules

Historically and currently, many engineering students in USA universities take technical communication modules, typically taught by English department educators (Connors, 1983; Yeats & Thompson, 2010). These siloed modules focus on professional genres such as reports, proposals, and presentations. While they prioritise awareness of rhetorical principles, they are often distanced from authentic engineering practice. Such modules may be less effective in convincing students that communication is central to engineering work.

Communication-intensive modules in engineering majors

Communication-intensive modules in the engineering majors embed writing and speaking tasks directly into disciplinary classes. This model helps students experience communication as integral to technical problem solving. Studies suggest that students are more engaged when assignments are tied to authentic engineering tasks (Paretti et al., 2014). This approach's success depends significantly on module design and sustained collaboration between engineering and communication staff.

Integrated curricula across multiple years

Integrated communicative instruction across multiple years of an engineering programme allows disciplinary genres to be addressed repeatedly in varied contexts, which supports long-term development and adaptability. This approach rests on the premise that communication cannot be mastered in a single module but must be reinforced and refined through the undergraduate experience. While integrated curricula have clear advantages, they also require substantial institutional coordination and staff commitment, which can make implementation difficult.

Supplemental approaches

A final category embeds supplemental engineering communication instruction via workshops, peer review programmes, process writing assignments, and communication modules in technical modules. These approaches offer scalable ways to introduce communication practice, particularly in large-enrolment contexts, and can strengthen students' abilities in revision, reflection, and collaborative feedback. While pragmatic, supplemental approaches nevertheless often provide limited and fragmented exposure to authentic engineering communication and may fail to cultivate the deeper rhetorical awareness necessary for professional practice.

1.2 Relationship between context and programme

These engineering communication pedagogy models take shape within larger regulatory and accreditation structures that influence how engineering curricula are designed and what learning outcomes must be demonstrated. In the USA, each university or college degree programme is allowed to create a path towards undergraduate degree completion with guidelines set by each state, and in many cases, national rules or guidelines also apply. For most engineering degrees, ABET sets the criteria for accreditation — an important benchmark that signals the quality of the degree. ABET approvals are mandatory for programmes that want their graduates to be eligible for professional licensure and to be competitive in the job market.

Cornell's Engineering Communications Program model

Across undergraduate engineering contexts internationally, communication is seldom “*authentically integrated*” in the engineering curriculum (Hutchison et al., 2021; Reave, 2004). Evans and Gabriel (2007) identified Cornell's Engineering Communications Program (ECP) as offering a new paradigm for teaching communication. Unlike skills-based or supplemental approaches, this model frames communication as social action inseparable from engineering practice. Communication genres are treated not as static templates to be mastered but as recurring forms of action through which engineers participate in professional communities; this practice, in turn, contributes to awareness of their ability to act as and be recognised as engineers. In practice, students work in teams on real engineering tasks for real clients when possible. In doing so, students' learning is situated by communicating in context and understanding communicative knowledge as part of their engineering problem-solving mindset.

1.3 Cornell's Engineering Communications Program history

We offer this brief review of our programme's context for you to see how we implement this approach. To graduate, all Duffield Engineering undergraduates must fulfil the Engineering Communications Requirement (ECR) (Cornell Duffield Engineering, 2025). Students may fulfil this requirement through multiple approved pathways, and ECP's core mission is to provide students with opportunities to develop communication skills that prepare them to contribute effectively in team-based environments across industry, academia, or other professional settings. Understanding ECP's positioning in Cornell's curricular structure (Fig. 4.11.1) may help you envision similar structures or engage actively in addressing your own university's allowances for programmatic positioning.

The ECR addresses ABET Criterion 3, which requires engineering programmes to develop in undergraduates “*an ability to communicate effectively with a range of audiences*”(ABET, n.d.). Steven Youra, the first director of ECP at Cornell, championed the ECR's creation, and the requirement went into effect in 1986/87. The second ECP director, Rick Evans, curated some unofficial but sustained relationships in the majors.

However, as enrolment and demand for communication instruction increased, educator workload became a pressing concern.

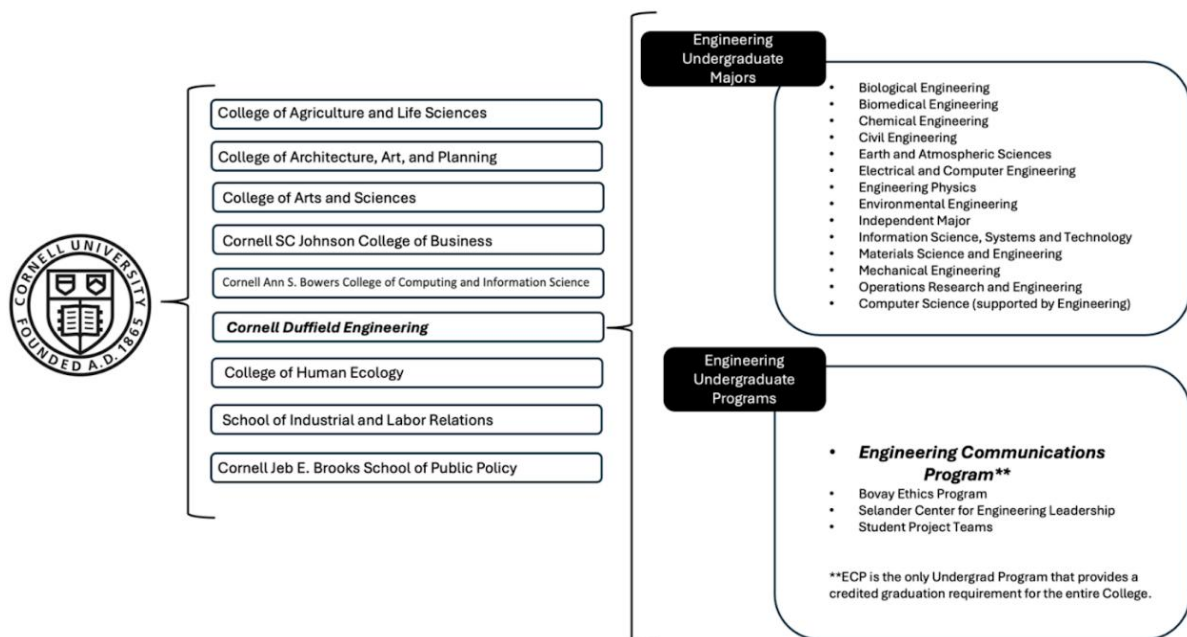


Figure 4.11.1: Cornell University's undergraduate structure (Own Work). Inside Cornell Duffield Engineering, the Engineering Communications Program is classified as an Engineering Undergraduate Program, reporting directly to the Engineering Associate Dean. Programmes can serve all majors.

With the models that we have outlined above in mind, you may be deciding which best fits your institutional context and is most feasible. Initially, ECP made ad-hoc instructional arrangements with engineering staff rather than creating official credit-bearing modules, which raised a few concerns. First, attaching credit to ECP modules made their importance clearer to students, ensured that modules appeared on transcripts and in graduation plans, and allowed staff labour to be counted in budgeting and staffing decisions. Second, ECP modules were added to administrative systems, like enrolment rosters, helping to account for instruction workloads in ways that both the institution and students recognised. In other words, you may find that formalising communication as credit-bearing work is essential for sustaining it. Therefore, after negotiating and mapping partnerships, ECP began attaching 1-credit (2 ECTS) modules to partnered engineering modules. Naturally, our first partnerships continued those already established relationships. While the entity responsible for approving the college curriculum was supportive of our efforts from the beginning, we advocate for finding allies within your own institution who are willing to do the same.

In the following sections, we outline the four *core communicative competencies* (CCC; see Conference on college composition and communication, 2018), which we suggest implementing when building the foundation of any engineering communication modules. Next, we describe ECP's programmatic model, logistics, benefits, and

potential complications, which you may also encounter in adapting a similar programmatic structure. Lastly, we provide a method for measuring students' communicative self-efficacy that, stemming from the CCC and supported by years' worth of results, we believe can assist you in similar programmatic or module-level assessment of communication instruction.

2 Core communicative competencies (CCC)

As a multidisciplinary field, communication can be approached from many theoretical frameworks, but ECP grounds its curricular and pedagogical approaches in four competencies: context, social action, design, and identity (Evans & Gabriel, 2007). Table 4.11.1 shows a brief definition of each competency as well as an approachable resource for you to introduce these competencies to your students.

Table 4.11.1: Core communicative competencies

<i>Competency</i>	<i>Definition</i>	<i>Resource</i>
<i>Context</i>	Communication is always context-bound. Context refers to the specific nexus of activities, means, and identities that makes communication as mediated social action possible.	'Rhetorical situation' one-page poster (Conference on college composition and communication, 2018)
<i>Social action</i>	When we communicate, we engage with others in communicative events, perform specific activities, and use any number of signs or symbols in order to get something done.	'Genre' one-page poster (Conference on college composition and communication, 2018)
<i>Design</i>	All communication reveals design, or structure and organisation, and the enactment of that design in performance. Multimodality has impacts on design.	'An introduction to and strategies for multimodal composing' (Gagich, 2020)
<i>Identity</i>	Communication as mediated social action is how we show ourselves to be legitimate members of a community, creating a credible and situated identity. It is how people engage in the legitimate performances of that community.	'Gee: What is discourse' YouTube video (Scott, 2014)

The theories we suggest expanding your familiarity with include:

- Situated learning and communities of practice (Lave & Wenger, 1991);
- Cultural-historical activity theory (Engeström, 1987; Vygotsky, 1986);

- Actor-network theory (Latour, 1987);
- Discourse analysis (Gee, 1990).

However, this theoretical and research-rich body of literature is quite time-consuming to read and comprehend, so at the absolute minimum, Paretti et al.'s (2014) work is a must-read to effectively and appropriately teach engineering students communication. Paretti et al. (2014, p. 606) succinctly summarise these theories.

Context. Communication occurs within a specific rhetorical situation comprised of 1) events for writing, labelled exigences ("*an imperfection marked by an urgency*") (Bitzer, 1968, p. 6) that prompts the need for coordinated action; 2) people (speakers, audiences, and their existing knowledge and beliefs); 3) media constraints and affordances; 4) cultural, social, and disciplinary conventions; and 5) audience expectations (Bitzer, 1968). Students analyse context features, adapting them to best shape their communication. Our understanding of communication practices draws heavily upon Bitzer's foundational article, which we recommend that you read as a starting point.

Social action. Within these rhetorical contexts, actors use strategic communication in order to cooperate towards goals. Bitzer (1968) argues for an understanding of rhetoric as a practice that promotes change in the world through organising the actions of collaborators. Building on Bitzer's foundation, Miller (1984) theorises genres of language use as "*typified rhetorical action in recurring situations*" (p. 159). Genres of language use are often thought of as written but also include spoken, such as "*the letter of recommendation, the user manual, the progress report, the ransom note, the lecture, and the white paper*" (Miller, 1984, p. 155). We also draw from the tradition of North American Rhetorical Genre Theory, which teaches students to analyse genres based upon their socio-historical contexts and ideology (Schryer, 2002). Importantly, we help students learn that genres are not fixed templates waiting for specific content; rather, they are socially constructed practices that change over time and must be adapted in each specific instance, and they are 'tools of cognition' central to the specific actions and goals of disciplines (Bazerman, 2009). We show students that analysing genres can help them better understand what social actions each genre accomplishes and how to deploy genres and specific rhetorical moves to accomplish their own ends.

Design. Communication can be strategically designed, and we present rhetorically based design principles for students to adapt and apply. Communicators almost always work within the affordances and constraints of specific genres, media, and their corresponding audience expectations, so we teach students to consider the trade-offs between conventions and innovations. Introducing students to communication design principles such as hierarchy, amplification, alignment, proximity, contrast, and repetition (Kress, 1990; Kress & van Leeuwen, 2001), which are relevant across modes and media, allows them to illustrate and explore organisational hierarchies in technical documents via headings and subheadings as well as in the design of graphs, figures, tables, slides, or posters. When students are taught to understand that communication occurs through multiple modes, such as visual, aural, spatial, gestural, and linguistic,

known as multimodality (Kress & van Leeuwen, 2001), they can identify and manoeuvre modes to complement their engineering goals and purposes.

Identity. The identity of the communicator both shapes and is shaped by design choices towards social action in a context. The abovementioned theories of situated learning in communities of practice highlight how novices in a field need to actively develop their disciplinary identity and they do this at least partly through developing their communication abilities across relevant engineering contexts, not only through gaining technical skills (Lave & Wenger, 1991; Vygotsky, 1986). Particular language patterns known as discourses are used to shape and perform identities in specific social contexts (Gee, 1990, 1999).

Several rhetorical theories explain how engineers develop their identities through communication (Agha, 2006; Anderson et al., 2010; Pare, 2002). First, engineers possess disciplinary knowledge that builds their 'situated ethos', referring to their reputation or credibility as an engineer situated within professional and personal communities, but they can also design their communication to develop their 'invented ethos' by performing specific language patterns and adapting their language appropriately according to their audience. Second, that performance of specific actions through language builds an engineer's identity. In other words, engineers make rhetorical choices depending upon the engineering context or situation that they are in. Successful identity building, therefore, depends on their ability to understand the needs of a context and the social actions that an engineer would perform within that context. As an example, if you are a structural engineer who designs bridges, you need disciplinary expertise to know what you're talking about, but you also need to sound like you know what you're talking about, not only to other structural engineers but also to other people who rely upon you to know and trust that you can design bridges.

Because communication is always tied to activities and purposes within specific contexts, it follows that for engineering students to truly learn to communicate as engineers, they need to practise communication within authentic disciplinary engineering contexts while using authentic genres to achieve authentic goals. Consequently, providing communication instruction within those authentic contexts is preferable, such as embedded in design projects or experimental research labs, rather than teaching communication separately, isolated from the activities of engineering.

While we teach communication both in embedded 'partner' relationships with engineering modules and in stand-alone communication modules, our goal is to promote and develop partner modules. In the stand-alone modules, we concentrate on teaching students the analytical skills (genre analysis, discourse analysis, design analysis) and strategic practices (identifying models, peer review) that will aid their continuing communication development in authentic contexts. In 'partner' modules we teach them these skills and practices and also scaffold their application in the context of their engineering work.

3 Curriculum design at Cornell Duffield Engineering

The robustness of ECP relies not only on the theoretical foundations of the CCC but also on the practical curricular structure and logistics that we also must contend with to offer communication instruction to engineering students. Accordingly, we shift our focus to how undergraduate students fulfil their engineering communications requirement (ECR). Enrolment data shows that most Duffield Engineering undergraduates (ca. 70% of students) fulfil the ECR by enrolling in and passing a module offered by ECP. To meet this need, ECP employs five full-time and one half-time teaching staff members.

In order for an authentically integrated engineering communication curriculum to work effectively, engineering and communication administrators and staff must be willing to cooperate and collaborate, respecting one another's areas of expertise. We believe you can establish fruitful partnerships between communication and technical modules, steps for which we describe in Section 3.3. We do not yet offer specialized training for this model, but we recommend that you hire staff with specific degrees and experience (see Section 5). We have found that experience teaching technical writing or communication modules is often insufficient; rather, candidates who are familiar with engineering curricula make a better match for this kind of engineering education.

Currently, students can fulfil the ECR via three methods:

- *Category A1*: stand-alone modules offered by the ECP (1-credit/2 ECTS or 3 credit/6 ECTS); includes independent studies.
- *Category A2*: partner modules, where the ECP attaches a 1-credit or 3-credit communications module to an engineering module.
- *Category B*: engineering modules designated as communication-intensive; these reside inside some engineering majors.

Because ECP does not control or assess modules in Category B, we will address Categories A1 and A2 in Section 3.2 and 3.3.

3.1 Student and staff workloads by module type

ECP's agile offerings provide traditional and specialised modules alike, all of which use the CCC, comparable credit workloads for students (see Table 4.11.2), and situated learning outcomes aligned with ABET.

ECP's stand-alone modules offer flexibility in curricular planning. At Cornell, a full-time teaching load is typically two 3-credit modules in both the Autumn and Spring semesters (referred to as a '2/2 load'). In semesters with a high number of graduating students, we can assign an educator who would normally teach two 3-credit modules to instead teach two sections of a 1-credit module in place of one 3-credit module (see Fig. 4.11.2). This adjustment keeps the educator's workload roughly equivalent while expanding capacity by providing approximately 24 additional seats in a given semester.

Table 4.11.2: ECP's 15-week standardised semester student workload. ECP student workload expectations are applied across all module types. Note the inclusion of multimodal communication elements, along with oral and visual communication, teamwork, research, and ethics form the core of each ECP module.

<i>1-credit/2 ECTS modules</i>	<i>3-credit/6 ECTS modules</i>
Write at least four significant assignments with a cumulative total of at least 1000 polished words by the end of the term (may include revisions, formal presentation notes, and traditional writing assignments).	Write, cumulatively, at least 3000 polished words by the end of the term. This word count can be spread over several assignments, and it assumes revision processes have been enacted.
Present at least two formal presentations (individual or team). One presentation may be a major technical presentation (recorded or live) for an interdisciplinary/varied relevant audience.	Present at least twice for review by the educator and/or peers. Presentations can be recorded or live, but they presume practice sessions and a final polished presentation.
Complete at least one assignment involving issues of professional ethics.	Complete at least one assignment involving issues of professional ethics.
	Research and provide information in ethically aware ways, including incorporating outside research with proper citations and dealing with AI impacts. Necessarily, this means that projects will require library database skills, at a minimum.
	Create multimodal, technically-focused artifacts that communicate information to audiences. This can include, but is not limited to, figures, tables, video, or other multimodal artifacts (such as 3D elements). These artifacts may or may not include generative AI.
	Participate constructively in a team project, where the essential skills of teamwork, communication, cross-cultural communication, and accessibility are enacted.

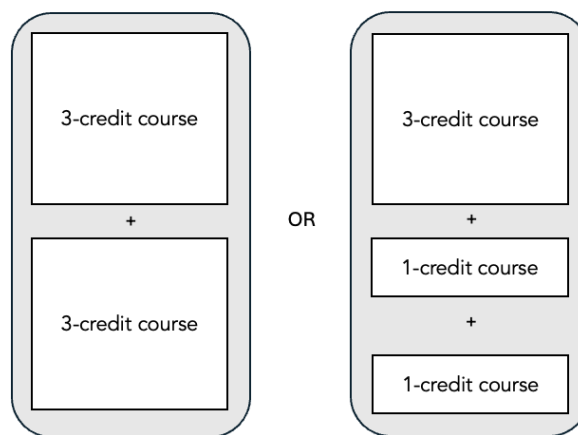


Figure 4.11.2: Workload for ECP staff by semester (Own Work). ECP deploys two flexible patterns of semester-based teaching workload. Seat demand influences which pattern is used for teaching assignments.

3.2 Stand-alone modules

Traditional stand-alone modules provide students flexible ways to fulfil the Cornell's ECR. Regardless of their credit load, all stand-alone modules incorporate the CCC in the work of drafting, revising, research, editing, presenting, creating visuals, and authoring multimodal communication artifacts. Students in all modules work both individually and in teams. Furthermore, workloads for staff and students are aligned across the programme and meet New York State Education Department requirements.

Stand-alone 3-credit modules

The story of our programme started with 3-credit modules, and for many years, ECP offered just two variants at the 3-credit level. We now have four 3-credit modules. We will concentrate here on ECP's foundational module, Engineering Communications, which had its inception in the late 1980s, continuing to the present. Engineering Communications is designed to help students think clearly about how daily work can be done effectively, efficiently, and professionally in the engineering, technical, and business sectors. It focuses on engineering communication skills that help boost students' career development in strategic communication, rhetorical skills, technical writing techniques, presentations, and collaboration.

Stand-alone 1-credit modules

At the time of writing, ECP offers three 1-credit (2 ECTS) stand-alone modules. Each module reflects the expertise of the respective staff who developed them and concentrates on specialised genres and theories.

3.3 Partnered modules

Our programme also offers partnered modules that are guided by Reave's (2004) term 'authentic integration', defined as "*the collaboration between instructors, in which at least one has technical expertise and another has communication expertise, to engage engineering students in a meaningfully unified course or project*" (Hutchison et al.,

2021, p. 923). Here, an engineering communication module is partnered with a specific engineering module within a major. The partnership structure can be envisioned as similar to a lecture paired with a lab section, where the engineering communication module functions as the applied component. Partner modules require coordination and are therefore complex in multiple dimensions.

If you are considering a similar model, developing or consulting a formal partnership guide may support implementation in your institutional context. To support the creation, maintenance, and dissolution of these partnerships, ECP has an in-house partnership guide that states: *"These partnered courses [modules] are close collaborations between dedicated ECP and engineering instructors. ECP faculty bring a wealth of knowledge, expertise, and experience about communication practices; they work closely with engineering faculty to understand field-specific expectations for students in the majors."* Hutchison's (2025) workshop paper on building and sustaining these partnerships may offer additional practical guidance.

While the impetus for these collaborations can vary, our experience has shown that you should lay a solid foundation by identifying required modules in your department's curriculum that either have communication deliverables assigned or in which staff wish to incorporate communication. When offering partnered modules, we strongly recommend requiring students to enrol in both the engineering module and the communication module so that students' and educators' effort and workloads alike remain fair and predictable.

Successful collaborations rely upon an initial meeting between communication and engineering staff to recognise the learning outcomes of the engineering module and how those can be met with relevant communication deliverables, which may already exist in the engineering module. During those early meetings, we recommend that you take advantage of the time to review the syllabus and/or a module calendar to get a sense of the learning outcomes and conceptual arc of the module. Good partnerships create learning paths in tandem. For instance, if the engineering staff assigns a final design report, then the engineering communication module will include activities and assignments that structure and scaffold that report in advance of the final due date, such as instruction in researching the literature or gathering primary insights, as well as a shorter design justification assignment in which students synthesise primary and secondary research and identify appropriate materials for prototyping their proposed design. ECP academic staff then offer focused written and/or verbal feedback on that written assignment to prepare students for the heavier lift of a more comprehensive technical document.

Accounting for instructional effort in partnered modules

Most ECP partner modules are offered at the 1-credit level. The addition of partnerships solidifies and documents the learning and teaching labour for students and involved staff alike. For staff, making the workload both documented and visible within the university system is of the utmost importance for reasons such as identified

field expertise, curricular visibility and positioning, service models, and promotion considerations.

Partner model pros and cons

When creating a partnered module, there are many common goals on the engineering side and the communication side. Briefly, partnering engineering and communication modules provides students with 1) situated learning via authentic projects (Artemeva et al., 1999; Poe et al., 2010); 2) structured teamwork via guided practices and agreements; 3) detailed iterative feedback cycles from peers and educators; and 4) situated engineering communication activities.

ECP holds these expectations for positive partnerships, where all parties in the partnership aim to

- Introduce students to and encourage their development of the ability to use the disciplinary variety of language for participating in their discipline;
- Offer students a theoretical framework for understanding communication that will allow continued lifelong communicative agility.

We also hold that partnered modules must be

- Rich, complex, and complimentary teaching and learning environments where students are exposed to situated communication experiences;
- Created with instructional partners whose good intentions are responsive to the demands and tenets of their fields and expertise;
- Balanced efforts to raise the impacts of module content and learning outcomes;
- Prime opportunities for pedagogical research.

For the most part, ECP has found wonderful working partnerships across Cornell Duffield Engineering. ECP has also experienced partnerships that needed to be dissolved due to shifts in module offerings in the majors, budgets, misaligned expectations, and differing pedagogical approaches.

3.4 Developing assignments and rubrics with the CCC

To see how the CCC framework operates at the module level, ECP staff develops rubrics to evaluate students' work for various assignments. We invite you to adapt Example 1, which provides high-level assignment criteria from a 1-credit (2 ECTS) professional portfolio website module. In this module, students write a final report to comprehensively explain their rationale for their website design and functionality. Each of the four CCC concepts intersects with module learning outcomes.

Example 1. Assignment criteria for rubric development

Multiple ECP staff members teach sections of Creating and Communicating Your Digital Professionalism. While our teaching styles differ, we mainly use the same set of assignments and rubrics to evaluate students' performance and assess their progress toward a fixed set of module learning outcomes. The rubric criteria below are each assigned a point value, but since you operate within a different teaching

context, we share just those criteria and leave grading methods up to you. Note that communicative concepts are in all caps.

Social action. Your website and multimodal content perform a credible social action or actions within the context (rhetorical situation) that you are responding to. Describe sequentially how you expect your primary audience to engage with this portfolio website. Explain how your chosen design promotes this engagement and potentially realises your desired outcome.

Context. Your website and multimodal content show thoughtful consideration of your professional context (rhetorical situation). Describe the premises/assumptions underlying your portfolio website and provide an evidence-based rationale that supports those premises/assumptions. Draw upon what you learned about genre conventions and any other relevant research.

Design. You create an intentional design that is responsive to context (rhetorical situation) and enables responsive action on the part of your primary (and, if applicable, secondary) audience. Explain how you designed your website and multimodal content to engage your intended audience. Cite what you learned from coursework as evidence.

Identity. You demonstrate a professional identity that enables the audience to ascribe appropriate abilities and attributes to you.

Multimodality: Your website showcases an awareness of multiple modes (visual, aural, gestural, spatial, and linguistic) and strategically implements these modes to complement one another, such that those modes are responsive to your rhetorical situation.

4 Assessing core communicative competencies

Since 2019, ECP has programmatically collected communicative self-efficacy (CSE) surveys to gauge students' confidence across multiple dimensions that map onto the CCC. Self-efficacy explains a person's agency to take action and achieve a positive behaviour or outcome (Bandura, 1997) and is measured in confidence levels which signify behaviours like goal setting, persistence, resilience in the face of failure, and more. Confidence generally shows how individuals represent those behaviours to themselves and others. Bandura's research method has influenced assessment of engineering students, as is shown by its use in engineering education: the American Society for Engineering Education conference proceedings show over 5,300 references to Bandura's work to date.

ECP's current director and the director emeritus created a 23-item survey with the goal of measuring students' confidence in their abilities to perform a variety of communication activities (Nathans-Kelly & Evans, 2017a). Each question maps onto the CCC. Following Bandura's (2006) pivotal research, each question prompts students to select their percentage of confidence on a scale of 1 to 100 (Nathans-Kelly & Evans, 2017b).

Like many educators, you might be subject to student evaluations of teaching. You may also be aware of research that shows their flaws, including bias towards educators of colour, women, and those who identify as 2SLGBTQIA+ⁱ (Shorter, 2023). Furthermore, such surveys are not able to offer a reliable metric of module quality or learning outcomes being met (Uttl et al., 2017). If you're looking for a more powerful statistical window into the effectiveness of engineering communication instruction, we offer our CSE survey protocol, which asks students to gauge their confidence in performing specifically identified communication skills.

4.1 How to replicate the survey and analyse results

Should you decide to implement a similar programme, we encourage you to replicate our survey methods described below in Example 2. We are also happy to provide a how-to guide on using an Excel spreadsheet with macros that assists with steps 2 and 3 below by contacting our lead author.

Example 2. Process for replicating the communicative self-efficacy survey

- 1. Send students the same survey at the beginning of the semester (pre-survey) and again at the end (post-survey). See Table 4.11.3 below for survey questions or our website (Nathans-Kelly & Evans, 2017b) for the full questionnaire. Collect student IDs or some other information that allows you to identify which students completed both surveys and match up their responses.*
- 2. The same students need to complete both the pre- and post-survey to conduct paired t-tests to see whether their confidence in their communicative self-efficacy produces statistically significant increases.*
- 3. Calculate effect size (Cohen's d) to measure the extent to which your communication instruction works. The difference between the same group of students — once at the beginning and again at the end of the semester — takes more than sample size and statistical significance (p -values) into account to see if there is practical significance, also known as real-world applications, of your study (Sullivan & Feinn, 2012). Large effect sizes ($d \geq 0.8$) mean that your instruction likely has real-world applications for students, indicating their confidence when communicating in future situations.*

4.2 Increased communicative self-efficacy

Our survey results across all module types indicate that students consistently demonstrate statistically significant increases in communicative self-efficacy. We have narrowed down these results to focus on average increases from two module types described above. Over the past six years (2019 to 2025ⁱⁱ), students in our signature 3-credit module Engineering Communications reported increases in the same seven questions, six of which showed large average effect sizes ($d \geq 0.8$) or real-world application. For the past four years (2022 to 2025), students in a 1-credit partner module, Communications for Practical Tools for Operations Research, Machine Learning and Data Science, showed significant gains in nine questions, seven of which also showed large or extremely large real-world applications.

While our full survey includes 23 questions, we concentrate on the 13 that are statistically significant year after year in either a 3-credit module, 1-credit module, or both. Overall, as Table 4.11.3 indicates, students from both module types succeed in giving presentations (Q8), slide design (Q9), and handling Q&A sessions. We suspect these results are owed to assigning students multiple presentations in a semester, regardless of their module selection, accompanied by readings from our director's coauthored book (Nathans-Kelly & Nicometo, 2014). In the engineering module that is partnered with our 1-credit module, students participate in a team project where they analyse a large dataset using operations research and machine learning tools and then write two reports. Therefore, the repeated appearance of Q11, Q13, and Q14 under the design competence offers evidence that students recognise learning outcomes focused on analysing and visualising data. Students in the 3-credit module persistently reflect self-efficacy in the design (Q2 and Q3) and context (Q5 and Q6) areas of communicative competence, perhaps owed to the robust semester-long projects that they typically complete in Engineering Communications.

Offering results from students in our modules alone may not paint a fully convincing picture that, in addition to giving engineering students communication assignments, communication instruction is also required in order to bolster this competence. To address this question, in the Spring 2025 semester, we collected surveys from students who took the 1-credit partner communication module; for comparison, we also surveyed students who *only* took the engineering module as a control group. The students who took both the engineering and the partnered communication modules more than doubled the number of significant questions (total of 16) compared to the control group. All questions had medium effect sizes or higher, with six questions showing very large effect sizes ($d = 1.0+$). By contrast, students in the control group had only seven questions with statistically significant increases, although all effect sizes were small to medium.

We tested for discrepancies between both sets of students' beginning-of-semester averages, but statistical testing yielded no significant differences between the two. In other words, there does not seem to be any proof that a self-selection bias exists among students who enrolled in both partner modules. These results give further credence to our authentically integrated communication curriculum: if we hope for engineering students to learn to communicate effectively, they must receive explicit instruction, preferably in the form of dedicated modules rather than the supplemental approaches mentioned in Section 1.1.

Table 4.11.3: CCC and survey questions with consistent increases by module type. Average increase was calculated by subtracting students' collective beginning average from the ending average. Only those questions are shown here that show statistically significant increases ($p \leq 0.05$) and large real-world applications (effect sizes or Cohen's $d \geq 0.8$).

<i>Communicative competence</i>	<i>Survey question I am ___% confident that I can:</i>	<i>Module type</i>	<i>Average increase</i>
<i>Identity</i>	Q1. express and represent my expertise in technical and professional contexts	1cr	13.9%
	Q23. be perceived as a knowledgeable and capable communicator	1cr	9.8%
<i>Design</i>	Q2. choose words and sentence structures	3cr	14.2%
	Q3. construct well-organised communication	3cr	12.6%
	Q11. design data visuals	1cr	13.3%
	Q13. create captions that interpret data and non-data visuals	1cr	15.1%
	Q14. integrate data and non-data visuals	1cr	16.1%
<i>Context</i>	Q5. write a first draft	3cr	14.1%
	Q6. revise beyond simple editing	3cr	12.5%
	Q8. give technical and professional talks and presentations	both	17.1% (1cr) 17.1% (3cr)
	Q9. use slide design strategically	both	13.8% (1cr) 17.1% (3cr)
	Q10. close presentations and answer questions	both	18.0% (1cr) 17.0% (3cr)
<i>Social action</i>	Q18. present technical information for multiple audiences	1cr	14.7%

5 Future outlook

ECP's authentic integration model where engineering and communication academic staff collaborate to design and revise modules is a practise that is not necessarily widespread within engineering colleges and programmes worldwide. Each academic year, ECP can teach up to 600 students in a wide variety of modules. With staff planning, ECP's curricular agility, and integrated CCC, we manage to meet increasing curricular demands. We strongly believe that if our small team can educate engineering students in communicative context, design, identity, and social action, so, too, can other engineering programmes. To do so, we recommend that you hire staff whose expertise includes rhetorical genre theory, technical and scientific communication, linguistics, rhetoric of science, and related fields, who have studied the complex integration of communication in technical settings. Perhaps most importantly for curricular agility, ECP hires staff who exhibit deep collaboration practices, investigate and comprehensively understand engineering module learning outcomes, and research how CCC complements and strengthens those outcomes. When hiring, we give preference to candidates who have a PhD in technical communication, professional communication, science communication, applied linguistics with a specialization in professional and academic discourse or related sector, or a related degree with a focus on communication, with competencies in teaching oral presentations and multimodal artifacts.

ECP academic staff teach modules where students develop and apply the CCC in team-based projects that enhance, highlight, and articulate their technical skills. Furthermore, we fully endorse Leydens' (2012) assertion that the technical cannot be extricated from the social, and communication is an integral part of any engineer's sociotechnical growth to gain professional and personal success.

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AI statement

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ⁱ In the USA, the term 2SLGBTQIA+ refers to Two-Spirit, Lesbian, Gay, Bisexual, Transgender, Queer or Questioning, Intersex, Asexual, and other identities under the + symbol. The addition of 'Two-Spirit' (2S) at the beginning of the acronym specifically recognises and honours the distinct, pre-colonial gender and sexual identities of Indigenous peoples, placing them before Western-defined concepts.

ⁱⁱ Exceptions from this analysis include 2020 when we did not collect data, as well as Spring 2024 when a data collection error occurred.

Part 5

Evaluating Needs,
Interventions, and
Outcomes of Transferable
Competencies and Skills

5.1

Evaluating and Researching Transferable Competencies and Skills

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This introductory chapter to Part 5 focuses on scholarship and research to evaluate the development of transferable competencies and skills. Evaluation and research of educational activities provide evidence of what, how, and why some outcomes occur. This knowledge could be used by stakeholders to improve education. It also helps to inform the engineering education community about areas that require attention and are worthy of further investigation, as well as to inform future practice through evidence. We start by introducing you to the scholarship of evaluation and research, as distinct stages in an inquiry continuum, before outlining the specific topics covered in this part of the handbook. In this context, we feel it is pertinent to establish why it is important to evaluate activities targeting the development of transferable skills and competencies in addition to the purpose of carrying out research on these topics.

1 Introduction

When designing Part 5 of the handbook, which focuses on evaluating needs, interventions, and outcomes of teaching transferable competencies and skills in engineering education, we intended this part to be the most advanced of the handbook, as it deals with assessing and evidencing the impact of our practices on students' learning. Therefore, this part is about reflecting on your teaching practice, and as such it takes you on a journey and guides you through the process of evaluating and researching your own teaching and its outcomes in a scientific manner. This journey starts by entering the realm of the educational sciences, since its approaches to research differ to those used within engineering, with which some of you may be more familiar (National Research Council, 2012). Therefore, as authors of the introductory chapter, we will not cover all areas related to this topic of evaluation and research in depth but aim to raise your awareness of some concepts and prepare the ground for you to start your own journey.

In this part, the authors aim to provide you with guidelines for evaluation and research at different scales; from learning activities in the classroom (nano level) to the larger scale of programmes at a single university, and universities at the national or international level (macro or supra level), zooming out to the comparison of transferable competencies and skills development across curricular contexts.

Chapter 5.2 raises the first fundamental question: what competencies and skills to include in an engineering programme and how to ensure that they are relevant for current and future professionals. Deciding this demands continuous alignment with industry and a mechanism to monitor the relevance of transferable competencies and skills for future engineering graduates. In Chapter 5.3, the authors provide you with a framework to evaluate programme level outcomes of competency and skill development. The next Chapter (5.4) is focused on the effectiveness on specific skill-based interventions within the classroom, how to evaluate the impact of an intervention, how to analyse and compare interventions for skills learning, and how to identify the impact of these interventions. Chapter 5.5 zooms out to a more macro level and uses a landscape analysis to make comparisons across different institutional contexts. In the final Chapter (5.6), you will learn more about sharing the findings of your scholarship and research into evaluation, and how the different ways of publishing influence the impact that your work has on the practice of others. The next sections in this Chapter will familiarize you with some evaluation and research principles covered in the rest of Part 5 and set the stage for you to continue your own exploration.

2 From educational practice to research

As part of your educational practice, you are often asked to look back, reflect on, and evaluate whether you have achieved the desired learning outcomes and the reasons why or why not. The use of evidence-based methods for evaluation can be really useful for this process of looking both back and forward. This is why, in this Section, we will introduce you to the world of inquiry and research in engineering education

and show you how this field may be of benefit to you when evaluating your own educational practice.

2.1 Why evaluate educational practices?

As an engineering educator, thinking about how to design learning experiences effectively for your students to develop competencies and skills may be the first step towards carrying out sound educational research. We see the process of improving education as one existing on a continuum of inquiry, where educators move in within it depending on their goals. Each stage of this continuum represents an increase in methodological rigour and public scrutiny moving towards growing engagement with empirical evidence.

Improving education starts with regular and effective teaching, as shown in the inquiry framework for research on engineering education by Borrego and Streveler (2014). Effective teaching focuses on using best teaching practices and content to improve teaching and in turn students' learning.

The next stage, after regular and effective teaching, is referred to as scholarly teaching, or, as described by Potter and Kustra (2011, p. 3): *"teaching grounded in critical reflection using systematically and strategically gathered evidence, related and explained by well-reasoned theory and philosophical understanding, with the goal of maximizing learning through effective teaching."* This is the first stage in approaching teaching and learning more scientifically by gathering evidence and assessing classroom practices to improve teaching.

Where scholarly teaching impacts the activity of teaching and the learning of the students, scholarship of teaching and learning (SoTL), the next stage in this continuum, contributes to scholarly knowledge in a more formal way (Richlin & Cox, 2004). SoTL is defined by Potter and Kustra (2011, p. 2) as *"the systematic study of teaching and learning, using established or validated criteria of scholarship, to understand how teaching (beliefs, behaviours, attitudes, and values) can maximize learning, and/or develop a more accurate understanding of learning, resulting in products that are publicly shared for critique and use by an appropriate community,"* or, as described by Boyer (1990, p. 23) in his founding work on SoTL, *"teaching both educates and entices future scholars"*. Borrego and Streveler (2014) emphasise that SoTL is an activity that leads to findings that can be evaluated and criticised publicly and thus leads to knowledge that future teachers and scholars can build on.

The final stage in the continuum is the discipline-based field of engineering education research (EER), which goes well beyond the practice of effective engineering teaching. Borrego and Streveler (2014, p. 458) describe three additional characteristics of EER respect to SoTL: it

1. *"Begins with a research question focusing on the 'why' or 'how' of learning (Paulsen, 2001);"*
2. *"Ties the question to learning, pedagogical, or social theory and interprets the results of the research in light of theory. This allows for the research to build theory and increase the significance of the findings;"*

3. *Pays careful attention to the design of the study, the methods used, the validity and reliability of the findings. This will enable the study to hold up to scrutiny by a broad audience, again creating a potential for greater impact of results”.*

It goes beyond the specific population of a specific classroom or a higher education institution — being able to draw conclusions for a broader population of learners characterises EER (Borrego & Streveler, 2014). These characteristics differentiate SoTL from EER.

EER is comparatively young compared to the more traditional fields of educational sciences and has only really started to grow in the past 40 years (Jesiek et al., 2009; Saunders-Smiths & Leandro Cruz, 2020). Contrary to much of the research that takes place in engineering, research in the fields of educational sciences and EER is characterised as low-consensus research (Power, 2021). This term describes fields or topics with significant disagreement among experts regarding theories, methodologies, and research questions, often characterized by diverse perspectives and conflicting findings. As such you should not be surprised if you find yourself in healthy academic discourse with colleagues on what is the best way to go forward. Dart et al. (2025) identify themes and subthemes that influence the development of a researcher in engineering education — environment, community, knowledge acquisition, and personal attributes — and make clear that the pathway from scholarly teaching to EER is a complex process that goes beyond the individual development of the researcher. If you are interested in diving deeper into this field, we recommend the *International handbook of engineering education research* (Johri, 2023), which is available as open access.

2.2 Levels and actors in evaluation and research of educational practices

The ultimate aim of an evaluation or research carried out in the context of engineering curricula is to improve education, as mentioned earlier. Education is an ecosystem with different actors that operate at different levels (van den Akker, 2003). Hence, it is important to consider the level at which evaluation or research is done within this ecosystem, as well as the actors involved and their respective perspectives (see Table 5.1.1).

You might be interested in how students acquire and further develop transferable competencies and skills (e.g., to collaborate, communicate, self-regulate) in relation to a specific activity within a module or in the classroom (nano level, Chapter 5.4), how transferable competencies and skills are acquired or developed over a period of time during a module (micro level), how transferable competencies and skills develop throughout an entire programme (meso level, Chapter 5.3), or how programmes across a university or a number of universities support the development of transferable competencies and skills (macro or supra-level, Chapters 5.2 and 5.5). The macro and supra level can also pertain to national or international actors, respectively, and can be linked to policy makers such as accreditation bodies (see Chapter 1.4 of this handbook). How you approach the design of the evaluation or investigation will vary depending on the level at which you operate. However, conceptually the approach for

designing a rigorous evaluation or research in learning are not context-bound. Therefore, many elements can be transferred and scaled from one level to another. We elaborate these points further in Section 3.

Table 5.1.1: Levels and actors within the educational ecosystem in the context of evaluation and research of transferable competencies and skills.

<i>Educational level</i>	<i>Actors' perspective</i>
Classroom activity (nano level)	Students, lecturers, educational support
Module (micro level)	Students, lecturers, educational support
Programme (meso level)	Students, lecturers, programme director, educational designers
University programmes (macro level)	Students, lecturers, programme directors, educational support, deans, local and national policy makers
Programmes across universities (supra level)	Students, lecturers, programme directors, educational support, deans, and local, national, and international policy makers

The understanding that is derived from evaluating the impact of an intervention or investigating an identified challenge in the context of skills and competencies can be useful to inform lecturers and educational designers (nano level) when designing future educational activities in the classroom (e.g., Mio et al., 2019). Likewise, understanding what works and how students develop transferable skills and competencies over the duration of a module, a problem, or a project (micro and meso level) can help educators and educational designers to consider the design of a coherent and cohesive curricula that supports thorough skills and competency development (e.g., Mabley et al., 2020). Finally, understanding what is effective in different programmes and university environments can help policy makers consider what needs to be in place to support the holistic development of skills and competencies at institutional, national (macro) and international (supra) level (e.g., Chans et al., 2025).

When looking at the different levels of the education ecosystem, it might be obvious which actors to involve (e.g., educators, programme directors, educational support, deans). Involving students in cycles of educational improvement is valuable to ensure that their educational outcomes and experience are enriched (Cook-Sather et al., 2014). Their involvement can be as participants in studies but also as co-designers of educational activities and subsequent participants in evaluation and research. This choice can have an impact on how the investigation is carried out, which necessitates ethical considerations, as we will discuss in Section 4.2.

Now that we have covered the reasons for conducting evaluations and research, as well as the actors involved and levels in which such activity can take place, we will

consider in more detail the ways in which the evaluation and research are designed and conducted.

3 Lines of inquiry and theoretical grounding

When considering EER as a field of research, it is important to start by clarifying the position of the theme in the EER field and that of the researchers. Fensham (2004) proposed criteria to position EER as a field of research. His criteria are grouped into structural, intra-research, and outcome categories, and are helpful in shaping the field of EER. When developing lines of inquiry, the intra-research criteria especially need to be considered (see Table 5.1.2).

Table 5.1.2: Fensham's criteria (structural, research and outcome) for defining the field of engineering education research (adapted from Borrego and Bernhard, 2011). Notice that only the research and outcome criteria are included here for relevance.

<i>Research criterion</i>	<i>Description</i>
Scientific knowledge	Knowledge of engineering and education required to conduct the research
Asking questions	Asking distinctive research questions not addressed by other fields
Conceptual and theoretical development	Theoretical models with predictive or explanatory power
Research methodologies	Invention, development or at least adaptation of methodologies, techniques, or instruments
Progression	Researchers are informed by previous studies and build upon or deepen understanding
Model publications	Publications that other researchers hold up as models of conduct and presentation of research in the field
Seminal publications	Publications recognised as important or definitive because they marked new directions or provided new insights
<i>Outcome criterion</i>	<i>Description</i>
Implications for practice	Outcomes of research that are used in the practice of engineering education

When setting up your research, these criteria support your approach and make you aware of how EER distinguishes itself from other fields. For example, when setting up research questions pertaining to the evaluation of transferable competencies and skills, you need to be aware of how similar questions have already been studied in related fields (e.g., science education, disciplinary education) and how your questions are relevant for developing transferable competencies and skills specifically in

engineering education. You can become aware of these through a literature review. Through the process of studying the literature, you also familiarise yourself with the theoretical grounding and the state of the art in related fields of educational research and can adapt them to your own EER. Svinicki (2010) provides a guide of theoretical frameworks in education and links these with common issues found in engineering classrooms and programmes in higher education. She subsequently formulates researchable questions. A theoretical framework, which interconnects ideas, concepts, and relationships of interest in the study, helps to inform the design of the inquiry (Magama, 2021). The theoretical framework not only comprises theories and models on learning but also consists of concepts and ideas derived from earlier research. Hence, a theoretical framework provides a good way to learn what has been done on the specific topic within and outside your field and allows you to ask questions that have yet to be answered and are worthy of investigation within your field.

The most prevalent theories used in research focused on the development of transferable competencies and skills recognise that learning occurs in connection with the social environment: social cognitive theory (Bandura, 1986), situated learning theory (Lave & Wenger, 1991), and social cultural theory (Vygotsky, 1978). Theories related to motivation and agency, such as achievement goal theory (Dweck & Leggett, 1988; Elliot & Church, 1997), self-determination theory (Deci & Ryan, 1985) and expectancy-value theory (Eccles et al., 1983), can also serve to inform research in relation to transferable competency and skill development. The choice of theory used depends very much on the topic or question at hand and the level at which the problem is situated (e.g., nano, micro, meso level).

4 Approaches to evaluation and research

When starting to formulate your evaluation and research process, it is important that you become familiar with what is already known about the topic and problem of interest through a literature study. Next, you can make a link between the problem and a relevant theory about how people learn. This process helps you to formulate the questions that guide your inquiry or research. By going through iterative cycles between problem analysis, theory, and questions, you refine your focus. We provide examples of general research questions, perspective and level, and theory in Table 5.1.3. For examples of evaluation questions and associated methodologies for educational outcomes and interventions, we invite you to read Chapter 5.3, section 5 and Chapter 5.4, section 4 respectively.

There are several ways in which the process of inquiry can be approached. Here, we will elaborate on different approaches to applied research that can be considered in educational contexts (McKenney & Reeves, 2018), as well as broader approaches that are generally used in research (Cohen et al., 2018; Creswell & Creswell, 2018).

Action Research (AR), Design Research (DR), and Educational Design Research (EDR) are considered applied research approaches. However, where the principal goal of AR is the systematic improvement of local classroom practice based on critical reflection through teacher inquiry (Metler, 2021), DR and EDR have the dual focus of improving

classroom practices and advancing theoretical understanding through the design and testing of interventions (McKenney & Reeves, 2018). Although in some of the literature a distinction is made between what characterises DR and EDR in regard to applied research in education, McKenney and Reeves (2018) use the term EDR as an umbrella term for all approaches to applied research that share this dual purpose. EDR offers three main inquiry orientations — research for, on, and through interventions — based on the implementation of a specific educational design, i.e., an intervention. In this sense, EDR is also considered an interventionist approach.

EDR follows specific steps or phases each involving the interaction between research and practice — problem analysis and exploration, design and construction, and evaluation and reflection — that are mostly considered in iterative cycles. Possible points of departure in the inquiry process could be (McKenney & Reeves, 2018):

1. When there is a change in the instruction design by means of an intervention, typically in response to an already identified problem in the classroom, that calls for evidence to ascertain if the intervention has met the goals based on the characteristics of the intervention design (i.e., research on interventions). Formulating question 4 in Table 5.1.3 in terms of the effectiveness of the intervention (i.e., 'how well does...') is an example of inquiry on an intervention.
2. When further understanding of the problem is necessary before a solution or an intervention can be designed (i.e., research for interventions), that will provide both theoretical understanding and input for intervention design. Questions 1 and 3 in Table 5.1.3 are examples of questions that seek to investigate and understand a situation before any intervention is designed.
3. When there is interest in understanding certain learning and teaching phenomena and an intervention can provide a means by which this can be studied (i.e., research through interventions). Question 4 in Table 5.1.3 focusing on the students' responses to the intervention is an example of inquiry through an intervention.

When you are interested in understanding a problem, the effect of an intervention or a phenomenon more broadly, you use a "*systematic, controlled, empirical and critical investigation*" of propositions and relations associated to the object of study (Cohen et al., 2017, section 1.2). In doing this, and particularly in the context of transitioning to EER, you are often challenged about your beliefs and position in relation to the nature of knowledge and how it is constructed (i.e., epistemology), your world view (i.e., philosophical perspectives), and your professional identity, for instance, engineer, educator, or educational researcher (Dart et al., 2025).

4.1 Research design

When designing research in general, it is important that your research approach considers the interactions between your views and belief about the nature of the research (i.e., world views), the type of designs, and the research methodologies (Creswell & Creswell, 2018). It is through research design that you attend to the formulated research questions guiding the inquiry. In doing so you follow a process

that systematically, structurally, and iteratively gives coherence to the research approach. Research design provides a blueprint that satisfies the research purpose (Cohen et al., 2017, section 7.1) and considers the alignment between a theoretical framework and methods of data collection, analysis, interpretation, and validation (Maxwell, 2013), ultimately rendering the approach coherent.

In practical terms, research design should align well with the questions formulated (what would you like to learn or know? What are the questions you have?), the methodologies used (how could these answer your questions? What type of data is useful in answering the questions? How and when do you collect the data? How do you analyse the data? What perspective do you use to interpret the data?), and the relevant theories and knowledge of the current state of the art (what is already known in this area or about these questions?) on the specific competencies and skills under investigation.

As the research question is a critical part of the inquiry process, we would like to elaborate further on this point. It is important to formulate questions that are relevant and useful, connected to the purpose, theories and knowledge of the field and topic, and that are clear, focused, and feasible. Examples of topics and general questions of interest, the perspective and level at which they are considered, and the possible theoretical approaches that could be used to inform the research design, are presented in Table 5.1.3.

In general, a good approach is to formulate one to two general broad questions for a project or study, such as those in Table 5.1.3, and a sequence of subsidiary questions (typically 1-7), each considering a single concept, phenomenon, or relationship addressing 'what', 'how', 'why', or relevant hypotheses (Creswell & Creswell, 2018; Ritchie et al., 2013). Research questions are generally classified as explorative, descriptive, comparative, hypothesis testing, and interpretivist or meaning-making questions. Depending on the type of question and the purpose of the inquiry, three types of research designs can be selected: quantitative, qualitative, and mixed methods (Creswell & Creswell, 2018). For instance, from the suggested questions in table 5.1.3, questions 2 and 3 involve the exploration of opportunities provided to students at programme level. Question 4 involves making sense of the actions of students working in teams to understand how a specific intervention helps them (and possibly why), making this a good example of an interpretivist question. Question 2 could also be intending to seek a description of the mechanisms supporting skill development at programme level. Questions 1 and 5 could be seen as intending to test a hypothesis or to establish causal relationships respectively, with the possibility of focusing also on explanations and descriptions. In all cases, setting sub-questions can help with further refinement as mentioned earlier.

Table 5.1.3: Examples of potential topics and questions of interest, the actor perspective and level in the educational ecosystems aligned with potentially relevant theories.

<i>Question</i>	<i>Actor perspective</i>	<i>Education level</i>	<i>Theoretical grounding</i>
1. To what extent do students in my module develop their leadership and interpersonal communication while working in teams?	Student learning	Module/ activity	Social cognitive theory (Bandura, 1986), experiential learning theory (Kolb, 1984)
2. How do current opportunities for students to work in teams in my programme contribute to their development of project management skills over time?	Student learning over time	Programme/ series of activities and interventions	Social cognitive theory (Bandura, 1986), socio-cultural theory (Vygotsky, 1978), expertise development - deliberate practice model (Ericson et al., 1993)
3. What competencies are essential for students in my programme to succeed in their internship?	Student/ workplace	Module/ programme	Situated learning (Lave & Wenger, 1991), social cognitive theory (Bandura, 1986)
4. How (well) does the 'workshop on teamwork management' at the beginning of my module help students to set up team processes?	Student	Module/ intervention	Social cognitive theory (Bandura, 1986), self-regulated learning (Zimmerman, 1986), socially shared regulation (Hadwin et al., 2018)
5. What is the effect of using online quizzes in the self-regulatory behaviour of first-year students?	Student	Module/ programme/ intervention	Social cognitive theory (Bandura, 1986), self-regulated learning (Zimmerman, 1986)

After the formulation of the research question and sub-questions, you should select the appropriate research design and methods. Features such as the nature of the research question and the number of participants can help in deciding what approach to take.

Quantitative designs and methods are preferred when a theory is being tested or the deductions about relationships and characteristics of the sample population are of interest. They are also a good fit when the population of participants is sizeable, as they allow for use of statistical analysis, which can be split in descriptive statistics, correlational analysis, and factor analysis (Borrego et al., 2009). Quantitative designs include experimental designs such as true- and quasi-experiments as well as non-experimental designs such as causal-comparative designs, correlational designs, and surveys (Creswell & Creswell, 2018).

Qualitative designs and methods are favoured when the research question is of a descriptive, explanatory, or meaning-making nature and tries to address 'what', 'how' and 'why' questions, which requires rich contextual data (Borrego et al., 2009). Qualitative designs comprise procedures from different perspectives, such as grounded theory, phenomenology, ethnography, narrative research, and case studies (Creswell & Creswell, 2018). Much of the data collected is conversational, textual, or visual, and is analysed through different approaches bound by the design procedure and theoretical framework. In comparison to quantitative designs, that are mostly dominated by deductive approaches, qualitative data analysis often follows an inductive approach, providing space for interpretivist perspectives which can be completed for the smaller sample of participants typical of qualitative studies (Borrego et al., 2009).

Mixed methods designs involve the combination or integration of both quantitative and qualitative designs. Some forms of mixed methods design are (Creswell & Creswell, 2018):

- *convergent parallel*. Looking to merge data to yield a comprehensive analysis;
- *explanatory sequential*. In which quantitative research is followed by explanatory qualitative research;
- *exploratory sequential*. In which qualitative exploration takes place in order to build a quantitative phase;
- *embedded*. That is, either convergent or sequential data are combined with complementary data;
- *multiphase mixed methods*. Employment of both concurrent and sequential strategies.

We want to emphasise that there is no such thing as correct or incorrect research method or design; instead, the right research design should be selected that will best answer the research question (Borrego et al., 2009). Methods and design should also satisfy the criteria for coherence in research (Maxwell, 2013), which state that there should be clear alignment and connection between the goals, the theory and state of the art, the research questions, the methods, and the validity of the results.

In any line of inquiry, be it for evaluating the effectiveness and impact of an intervention at different levels or for understanding an issue or phenomenon in the classroom, the process involved in planning is very similar. Later in section 4.3 (Table 5.1.4) we touch on examples of approaches that could serve to guide evaluation and research designs making explicit distinctions between broad questions, level, target groups, and research design and methods. You will also find examples in the subsequent chapters of this part that elaborate on these points.

4.2 Ethical considerations

In preparing an evaluation or research design it is important to consider the ethical aspects of the inquiry. Ethical dilemmas might appear because of the nature of the research (e.g., involving minority groups), the contexts, procedures, methods, and type of data collected, the characteristics of participants (e.g., students with specific learning needs), and manner in which data might be used in the dissemination of results (Cohen et al., 2017, section 7.1; Sochacka et al., 2018). All these need to be considered in research design and planning. While designing and planning your research, it is essential that you consider how to communicate with stakeholders to clarify the reasons for conducting the investigation, the activities that this entails, and how the outcomes will help in further improving the educational setting. These actions help participants to make informed decisions about their participation in your research. In many cases the participants in a study are your own students, and in such cases, it is important to clarify to them how any potential conflicts of interest and power relationships are being addressed. For instance, if the target population are students in your module, how would you reassure students that their grades will not be affected by their participation (or lack thereof) in a study? In such cases, asking students to consent to participate (informed consent) does not sufficiently address ethical aspects. We will not cover how to address ethical dilemmas in EER in detail here. However, following institutional codes of ethics and procedures for ethical approval is essential for carrying out research in a responsible manner. We encourage you to apply for ethical approval early, as the process can help you to clarify many of the details related to the execution of the research (e.g., dealing with privacy, power imbalance, data management and storage) and ensure that you pay attention to any potential impact on different student groups. Higher education institutions have policies and procedures that help to fulfil ethical expectations and ensure legal compliance for investigations dealing with human participants. Note that ethical approval takes time and is a process better started earlier to ensure that this is in place before you start with any data collection. In addition, if you wish to publish the findings of your work, having obtained ethical approval is a requirement by many publishers.

4.3 Examples of evaluation and research design and methods in the context of transferable competencies and skills

Examples of broad research questions used to guide the selection of research design and methods, as well as the data collection and analytical approaches to data, are presented in Table 5.1.4.

Table 5.1.4: Examples of potential research designs and methods relevant to broad research questions on transferable competencies and skills at different levels and with different perspectives. Note: the methods proposed here are by no means exhaustive and are intended as examples only.

<i>Broad question</i>	<i>Design</i>	<i>Methods: data collection and</i>	<i>Methods: analytical approaches</i>
1. To what extent do students in my module develop their leadership and interpersonal communication while working in teams?	Quantitative Mixed: explanatory	Survey instrument, interviews, focus groups, observations, documentation	Statistical analysis (descriptive, inferential) explanatory analysis (grounded theory, qualitative content analysis, thematic analysis)
2. How do current opportunities for students to work in teams in my programme contribute to their development of project management skills over time?	Qualitative	Longitudinal interviews, documentation	Narrative analysis, interpretative phenomenological analysis
3. What competencies are essential for students in my programme to succeed in their internship?	Mixed: exploratory	Interviews, focus groups, surveys, Q-methodology	Case study analysis, thematic analysis, Q-methodology, descriptive and inferential statistics, exploratory factor analysis
4. How (well) does the 'workshop on team-work management' at the beginning of my module help students to set-up team processes?	Qualitative	Interviews, exit cards, focus groups, observations, documentation	Qualitative content analysis, thematic analysis
5. What is the effect of using online quizzes in the self-regulatory behaviour of first year students?	Quantitative Mixed: convergent embedded	Survey, online analytics, interviews	Sequential analysis of online trace data, descriptive, inferential and comparative statistics, thematic analysis

As mentioned earlier, the questions should be aligned with the theoretical foundations that guide the inquiry. Ultimately, preparing a research design is an iterative process. For more about research methods in engineering education, we recommend the upcoming *International handbook of engineering education research methods* (Johri et al., n.d.) and Dewar et al. (2018) and for general education research works by Bakker (2018), Creswell (& Creswell (2018), Cohen et al. (2017), Mertler (2024), and Svinicki (2004).

4.4 Quality criteria for EER

In designing evaluation and research approaches to study education in competencies and skills, it is important to recognise some of the aspects that influence their development. You know that much of the learning takes place outside the classroom and as such it is influenced by external factors that are not possible for you to control or to capture. This is of particular importance when trying to use control groups in an experimental or quasi-experimental design, where you aim to establish cause-effect relationships. Similarly, when using qualitative approaches where students self-report or must recall past experiences, the data might be biased as it is contingent on students' own beliefs and values. Learning is a social activity and as such many factors affect the sense making, knowledge construction, and competency development of individuals. Likewise, when using surveys, the participants might be representative of only a part of the student population, potentially skewing the results. To strengthen the quality of research, a good strategy is to use different sources of data (i.e., data triangulation). Therefore, when making claims and attempting to generalise findings from your research, you must be open about the potential limitations which could arise from assumptions made, methods of data, and/or analytical approaches.

There are quality criteria that help establish the validity, reliability, objectivity, and generalizability of quantitative designs and the equivalent credibility, dependability, reflexivity, and transferability in qualitative designs (Borrego et al., 2009). It is important therefore to consider these at all stages of the evaluation and research process. To learn more about this, we have provided you with our recommendations of some of the more general literature on research design, research in education, and engineering education research, which you can find in Section 4.3.

5 Informing practice

We invite you to continue reading this part of the handbook to learn more about specific examples and cases where evaluation and research of competencies and skills have been carried out. Firstly, with respect to evaluating the relevance of skills, Chapter 5.2 presents cases in three different contexts (engineering skills in Finland, in the timber construction sector at different levels, and in the nuclear industry in Australia) where relevant skills were identified via various evaluation frameworks and approaches. Secondly, relevant to the evaluation of programme outcomes, Chapter 5.3 shows an approach to evaluate the attainment of competencies and skills developed from quality assurance frameworks, using student assessment data. Following on to consider the evaluation of activities and interventions, Chapter 5.4, on

evaluating interventions that develop transferable competencies and skills, offers a clear and practical guide to carry out the evaluations of interventions implemented at classroom level (case 1) and programme level (case 2). When it comes to institutional and cross-institutional perspectives, Chapter 5.5 presents approaches to carry out reviews: comparisons within and across institutions are exemplified by a case focused on the instruction of communication across institutions in Canada. Relevant to sharing the findings of your work is Chapter 5.6, which showcases how to report and disseminate findings from evaluation and research that help in building knowledge and contributing to the redesign of education activities to improve the quality of educational practices.

We invite you to experiment in evaluating and researching your own teaching and to reflect on your own approaches. Most universities have a Centre for Teaching and Learning where you can find more information and context specific support. The SoTL international community (International Society for the Scholarship of Teaching and Learning, n.d.) is also a source of inspiration, information, and support. You might also want to check local SoTL institutional or national networks that connect education researchers or consider attending one of the various Engineering Education conferences, such as our own SEFI annual conference. As mentioned in Chapter 5.6, conferences offer a supportive environment in which to first disseminate your own scholarly activity by presenting and publishing your evaluation findings. It is our hope that this and subsequent chapters will help you in taking the first steps to becoming a reflective educator.

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AI statement

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5.2

How to Evaluate the Relevance of Skills and Competencies

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This chapter discusses the rationale and means to evaluate the relevance of transferable competencies and skills for engineering degrees. It presents three processes that have been used in different contexts to identify which transferable skills and competencies are needed in engineering work. The cases also illustrate how the viewpoints of different stakeholders can be brought to the table. Although the evaluation of the relevance of skills may be more pertinent to programme heads and other educational leaders responsible for the construction of entire degrees, knowing about these processes and their outcomes can also benefit lecturers of a single module by showing where some of the requirements set for the teachers originate from and how they are justified. The chapter finishes with recommendations for those who wish to conduct an evaluation of relevance in their own context.

1 Introduction

This handbook rests upon a belief that transferable competencies and skills are essential in engineering and should be taught and assessed as part of engineering education. Therefore, in this chapter we aim not so much to convince the readers that evaluation of relevance of transferable competencies is needed, but to shed some light on how this might be done. Unlike the assessment of competencies (see Part 3 for assessment methods), which is often conducted by individual teachers and targets individual students, the external evaluation of relevance of competencies is more appropriately conducted at the level of modules or degrees and by groups of different stakeholders in order to get a more comprehensive understanding of the situation. Consequently, the contents of this chapter may be of more interest to programme heads and other educational leaders than to lecturers. Nevertheless, lecturers can also benefit from knowing about the evaluation processes and their outcomes, as this illustrates where the requirements for teachers originate and how they are justified.

Engineering innovation can be fast-moving, whereas adjustments to curriculum can be a slow process. Yet educators must continually be in touch with what is happening in industry in order to know how educational content should be adjusted to support new technologies, development trends, or industry practices. Educational leaders and administrators must also ensure that monitoring processes accurately reflect the need to embed these innovations in curricula. At the same time, transferable competencies and skills (e.g., communication, collaboration, critical thinking, leadership) and habits of mind remain essential yet often still underemphasised or only addressed in the 'hidden curriculum,' which refers to the often-implicit assumptions, norms, and values inherent to engineering education that are not made visible in the formal curriculum (Paul et al., 2022).

The research literature on employability in engineering education shows a wide consensus on newly graduated engineers' need for transferable competencies and skills, as well as on their relevance to the engineering curriculum. Less agreement, however, exists with respect to the emphasis that the teaching of transferable competencies and skills should receive in education, especially in relation to how transferable skills can or should be taught alongside technical skills and competencies (Winberg et al., 2020).

The significance of transferable competencies and skills to employability and the relevance for engineering curricula seem to be predominantly discussed from the viewpoint of industry. Student perceptions have also been studied to some extent (Murthy & Machel, 2021). Less is known about the views of the academics. However, some research suggests that their perceptions of the importance of various skills and competencies in engineering differs somewhat from the views of both graduates and industry professionals (Pyrhönen et al., 2019). This situation may make it difficult for educators to determine which competencies and skills are relevant to teach.

Like the earlier chapters of this handbook have revealed, there is no universally accepted definition, framework, or list of transferable competencies and skills in

engineering (see Chapter 1.3 for the myriads of alternative existing competency frameworks). This is also demonstrated in research on their relevance. Sometimes the transferable skills and competencies are studied as a whole, referred to by terms such as professional skills, soft skills, transversal skills, etc. Sometimes they appear as a long list of specific non-technical skills, either separately or alongside a list of technical or engineering-specific skills. Often, the research focus is only on one transferable skill or competency or on a specific group of them, such as the cluster of communication skills that includes written, verbal, and aural communication. This makes research findings difficult to generalise or apply within particular programmes or to concrete challenges of curriculum development. Still, joining up what is needed by industry, what is taught by educators, and what is perceived to be important by students remains a challenge.

Essential to overcoming this challenge is knowing which skills and competencies are relevant to be taught in engineering education. As different stakeholders may view the relevance differently, it is also of great importance to recognise the differences and reconcile varying views. This creates a need for good methods and practices to collect information and facilitate discussion between the different stakeholders. This chapter introduces three examples of processes that aim to capture and monitor the relevance of transferable competencies and skills in engineering education in a way that enables timely and effective development of curricula and pedagogy of engineering programmes.

In the rest of this chapter, we begin by setting the context and discussing why a continuous evaluation of the relevance of various skills and competencies (including transferable skills) is needed in engineering education. We then present three different ways in which this evaluation bringing in relevant stakeholders has been conducted in various contexts. The cases come from different geographical locations (Finland, the UK, and Australia), emphasise various stakeholder perceptions (graduates, industry, and professionals) and consider education from a variety of angles (engineering in general, timber in construction, and nuclear engineering). Next, we analyse the cases to identify implications and recommendations for practice and conclude with recommendations for further reading and resources.

2 Context

The question “*which skills are relevant in engineering?*” is probably as old as any form of training to be an engineer. However, the perceptions of the need for transferable competencies, and of the kind of transferable skills needed, is likely to vary greatly depending on the context of engineering education.

Martin et al. (2023) distinguish between five different orientations within the history of engineering education: scientific, market, social, political, and ecological orientation. Scientific orientation sees engineering as applied science, or the quest to solve technical problems with the help of scientific theories. Market orientation opposes the scientific orientation by emphasising the needs of industry over the imparting of scientific knowledge. It is characterised by discourses of employability

and entrepreneurialism. Social orientation is a more recent approach which stresses the social role of engineers and strives to develop engineering graduates' identity as citizens and community members. Political orientation shares the objectives on societal engagement and contribution to public good with social orientation, but with emphasis on top-to-bottom measures like policy and regulation and political decision making, instead of the bottom-up approach common in social orientation. Finally, the most recent orientation, the ecological orientation, focuses on advancing sustainable development especially from the viewpoint of environmental sustainability.

The relevance of transferable competencies and skills looks quite different from the perspectives of the five orientations. Scientific orientation appears not to put much weight on transferable skills. A systematic literature review by Winberg et al. (2020) noticed that although employability literature arguing in favour of a strong technical knowledge base did not deem employability unimportant, it emphasised the relevance of the disciplinary core in enhancing employability. In contrast, in market orientation certain transferable competencies play an important role, which is illustrated in frameworks such as EntreComp and the CDIO syllabus (see Chapter 1.3 for more information about these and other competency frameworks). Like market orientation, social, political, and ecological orientations all seem to stress various transferable skills and competencies but with different levels of emphasis. Hence, the suitability of a particular competency framework or other kind of definition of required skills and competencies is heavily dependent on the educational orientation prevailing in the country, discipline, institution, or programme.

Other factors that change engineering work and the requisites for engineering education regardless of the orientation need to be taken into consideration when determining the relevance of transferable skills. One of these is technological development, which especially in the field of ICT has had a great effect on engineering in all disciplines. The current era, often referred to as the fourth industrial revolution, the digital revolution, or the digital era, started in the 1970s and 1980s. It has been characterised by the widespread use and development of digital technologies, particularly the internet and computers, both in free time and in working life. The latest advancement in this realm is generative artificial intelligence (GenAI). Engineers Australia (Bell, 2025, p. 2) anticipates GenAI to elicit many kinds of changes to engineering work and therefore set new challenges for education: "*The growth of AI in engineering allows some of the traditionally labour- and cognition-intensive tasks to be delegated to these new technologies effectively. At the same time, it elevates engineers' responsibility to do so with wisdom, and to apply engineering skills to higher-order tasks. ... To harness AI effectively, we need the right education settings, ensuring the next generation of engineers are trained in the ethical and responsible use of these systems*".

Digitalisation in general and the growth of GenAI in particular thus come with requirements for yet another set of both technical and transferable competencies needed in engineering.

3 Approaches to evaluate the relevance of skills & competencies

Deciding upon which transferable skills and competencies to focus on in any engineering programme is not the only challenge related to the evaluation of their relevance. Other questions to consider include aspects like who should be involved in the evaluation, how to ensure the timeliness of the data, which fields and disciplines to look at, and how to ensure that the evaluation results are actually used in educational processes. In this section we introduce three different examples of how the evaluation of relevance of skills and competencies is carried out in different contexts (engineering in general, theme-specific, and field-specific), yet all resulting in an effective process with genuine impact on the delivery of engineering education

Table 5.2.1: The primary processes for data collection and analysis and taking action used in the three cases of the evaluation of relevance

<i>Case</i>	<i>Focus</i>	<i>Methods for collecting data</i>	<i>Methods for analysing data</i>	<i>Processes for taking action</i>
<i>TEK</i>	Skills and competencies in university level engineering degrees in Finland	National annual survey administered to all engineering MSc graduates	Descriptive statistics of distinct skills and competencies, and of groups of competencies; group comparisons enabled through interactive visualisation	Yearly seminar for discussing the results; Workshops in all participating universities; faculty/degree programme-specific procedures (e.g., workshops)
<i>NMITE</i>	Skills and competencies for timber construction professionals at many educational levels	Stakeholder workshops and roundtables culminating in an industry-agreed framework	Evaluation of learner achievement of framework competencies across a series of short courses	Feedback from Employer Advisory Group; faculty workshops; programme accreditation procedures
<i>UNSW</i>	Knowledge, skills, attributes and competencies for nuclear engineers in Australia	Define Your Discipline (DYD) workshops for professionals	Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), a multi-criteria decision making (MCDM) analysis method	Integrating results in the curriculum design processes at UNSW

All cases use different processes for collecting and analysing information, as well as turning it into educational development actions, while ensuring the industry involvement. These processes are summarised in Table 5.2.1. More details on how to scientifically approach the process of data collection and analysis can be found in Chapter 5.1 of this handbook and more information on accreditation and associated processes can be found in Chapter 1.4.

3.1 Case 1: national evaluation and monitoring of the relevance of skills in all MSc-level engineering skills (TEK & Finnish universities)

The first case study illustrates national cooperation in the continuous evaluation and monitoring of the relevance of the skills and competencies taught in Finnish engineering degrees. This process is based on the annual collection of data from recent graduates. This data is analysed and published centrally, and it is discussed within and across all universities providing engineering education to identify areas for improvement.

The TEK Graduate Survey (TGS) is an annual nationwide study conducted by Academic Engineers and Architects in Finland (TEK) in collaboration with Finnish universities. TEK is responsible for carrying out the survey, while the universities are responsible for reaching their new graduates. The feedback and results are utilised in developing university education and influencing educational policymaking. The cooperation started in 2011, and has thus accumulated a significant amount of data, which allows for many analyses from different perspectives.

The survey is one of the most extensive graduate feedback mechanisms in Finland, offering valuable data for universities, policymakers, employers, and students alike. It plays a crucial role in evaluating the relevance of higher education, identifying skill gaps, and supporting the development of engineering education to meet the evolving needs of society and the labour market. The main themes are study experience, thesis work, employment status, salary, job satisfaction, and future plans. The target group in the TGS are graduates with an MSc in Engineering or Technology or an Architecture degree from Finnish universities. The survey is open continuously and is administered to the respondent at a specific moment in their graduation process: when they have completed their studies and apply for graduation. Therefore, the survey results primarily offer a student perspective. Every year, thousands of graduates respond, with rates often exceeding 60%. The survey is available in three languages: Finnish, English, and Swedish.

As part of the study experience theme, TGS explores over 30 skill areas. The data shows: 1) how important graduates perceive each skill to be in their careers, and 2) how well their education prepared them in those areas. Other questions, such as areas for improvement and the benefits of education, also provide insights into the importance of skills or their acquisition during studies. The skill areas can be examined individually or by dividing them into six groups (with three to nine areas of expertise per group): 1) working life skills; 2) analytical skills; 3) social skills; 4) communication

and information processing; 5) expertise and substance knowledge; and 6) business and management. With the exception of expertise and substance knowledge, all the skill areas can be regarded as transferable competencies and skills.

Results are published yearly as an interactive visualisation, which enables anyone to filter the data by university, field of engineering, age (under or above 35), gender, and nationality (Finnish or non-Finnish), and view the importance and development of specific skills or skills groups either separately or in relation to each other. Universities receive all the data regarding their respondents as well as a basic analysis of the data. All data is available for research purposes upon request. Another interactive visualisation with the same filtering possibilities is available for the past five years of data.

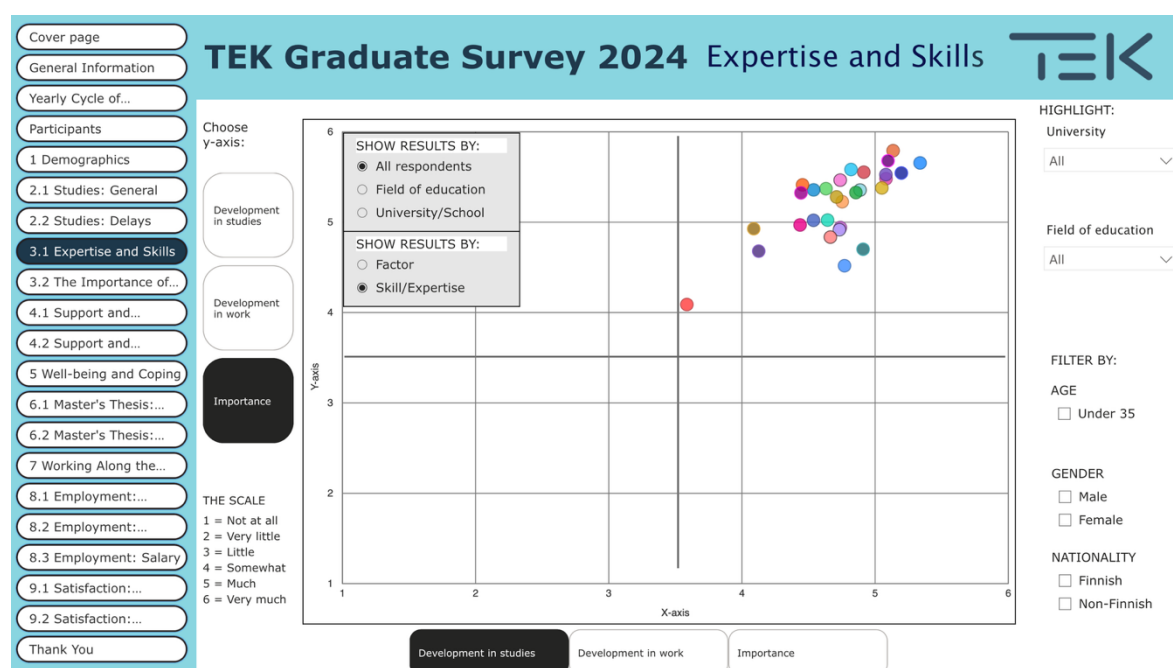


Figure 5.2.1: Screen capture from the interactive visualisation of the TGS data. From TEK graduate survey 2024. Interactive visualisation by TEK (2025). Copyright TEK, used with permission, no further use allowed.

A snapshot of the TGS results from the year 2024 (see Fig. 5.2.1) reveal that for all engineering MSc graduates in Finland, the skill area deemed least important was entrepreneurial capacities, while problem solving was the most important. The skill area where the development need was the greatest (the score for importance of a skill is higher than the score for development) was looking after their own well-being and the least (development greater than importance) were mathematical and natural science, and knowledge of the history and development of their own field.

The long tradition of surveying, nationwide data collection, continuous process, and high response rates have yielded comprehensive data which allows for detailed

monitoring of the graduates' perceptions of the importance of different skills as well as their acquisition during their degree.

The survey reveals that in the year 2024, approximately a quarter of respondents already had over two years' work experience in their field, and over a third had one to two years' experience (TEK, 2025), suggesting that the results also provide insight into the views of early-career engineers (Naukkarinen & Bairoh, 2022). One fifth of the respondents entered the MSc programme with a BSc degree from a university of applied sciences (TEK, 2025). These graduates often work as engineers in between their first (BSc) and second cycle degree (MSc). It is also customary, especially for the Finnish students, to work part-time during the last years of their studies, contributing to quite extensive work experience at the moment of graduation. Both these factors suggest that the results reflect not only insights gained from education but also some first-hand experiences from the industry.

The results are discussed among the whole engineering education community in Finland in a yearly seminar as well as in university-specific events, where the focus is naturally on the university's own results, but the expertise from TEK brings in insights from general trends and interesting benchmarks. In addition to university-specific events, the results are built into the quality assurance processes of universities in various ways. For example, in Lappeenranta-Lahti University of Technology (LUT) the degree-specific survey results are further analysed and discussed in yearly feedback workshops, where they are brought together with feedback data from other sources to indicate improvement needs and actions for the coming year.

Naturally, there are also limitations to the TGS process and the data it produces. The TGS data stored in the system and accessed through visual illustrations is quantitative. Therefore, it can only answer questions regarding which skills and competencies are important to engineering graduates, but it does not explain why. Although the survey includes some open-ended questions, respondents are not prompted to comment upon the relevance of skills and qualitative data regarding the issue remains scarce. TGS data contains the perceptions of newly graduated engineers, but while many of them already have some experience of engineering work, the responses do not represent the viewpoint of industry, which can only be gathered from experienced engineering professionals and managers. The nature and formulation of the TGS is quite general, which comes with the risk of the respondents answering according to their espoused theories rather than more context specific theories-in-use, meaning that their answers may reflect what they think they should say rather than what they actually think or would advocate in practice (for more information about espoused theories vs. theories-in-use see e.g. Argyris & Schön 1974). Finally, to keep the results comparable in time, the evaluated skills areas are seldom modified or changed, which can make the process slightly rigid in terms of addressing rapidly evolving needs.

Monitoring and responding to evolving skill demand in engineering education remains an ongoing challenge. Annual surveys like TGS can offer a structured and data-rich approach to understanding graduates' perceptions of skill relevance and preparedness. With broad scope, consistent methodology, and high participation

rates, surveys such as TGS serve as cornerstones for evaluating the alignment between academic training and labour market needs. The insights gained from the survey support curriculum development, institutional quality assurance, and national education policy. To further enhance their impact, future efforts should integrate qualitative methods to better capture the real-world applicability of skills and inform the strategic development of engineering education.

For more details on the process as well as the results obtained in recent years, we recommend reading the research part of the website of the Academic Engineers and Architects (TEK, 2026).

3.2 Case 2: industry-defined skills framework to advance the use of timber technology, engineering, design, and construction for a sustainable built environment (NMITE, UK)

The second case study describes the development of an expanding portfolio of short courses aimed at industry professionals and a new BSc focused on the sustainable built environment. The skills framework was created in cooperation between two higher education institutions, industry, and trade organisations to align educational offerings with sector-specific skills in timber technology, engineering, design, and construction. The process of defining relevant skills and creating courses in response formed the core of the development process.

Industry reports a pressing need for both transferable and specialist skills to achieve a sustainable future. It is unclear how many university courses currently integrate knowledge and skills specifically related to innovative timber products, designing with timber, and timber construction methods into relevant programmes (e.g., civil and structural engineering, construction management, architectural technology, etc.). However, as recently as 2021, a Canadian survey called for more specialised mass timber courses and at the very least the integration of these topics into existing courses to augment the content on steel, concrete, and masonry (Daneshvar et al., 2021). The Green Skills Survey by the UK Institution of Engineering and Technology (IET) indicates that “*a lack of skills is the biggest barrier to meeting net zero*” (IET, 2023, p. 9). Out of the ten countries surveyed, a lack of appropriate skills at both the management and workforce level is consistently cited as a top three priority, and these are often identified as transferable skills. For example, UK respondents reported that while 18% of people entering the workforce are missing technical or engineering skills, 36% are missing the skill ‘whole systems thinking’.

In creating a sustainable built environment, retrofitting existing buildings and delivering future housing and infrastructure demands a productive, regenerative, and collaborative approach that requires a shift to the use of sustainable materials, new forms of manufactured construction systems, and innovative digital technologies. The UK Government’s presumption in favour of these modern methods of construction (MMC) was underpinned by the launch of a Timber in Construction Roadmap (UK Government, 2025), which cites the need for new education and training models for reskilling and upskilling existing and entrant-level labour. These workers will need an

understanding of the materials and a unique approach to scheduling, skills, and management which are different from other traditional forms of construction.

Given the historic educational emphasis on carbon-intensive materials, and the arrival of new technologies like building information modelling (BIM) and VR/AR, current built environment professionals will need continuing education to enact the required changes in practice. They also need a more holistic understanding of building performance to ensure healthy, durable assets, as well as a suite of transferable skills in communication, sustainability, and ethics. In the UK, no further or higher education courses currently offer timber construction training focusing on MMC with clear pathways towards membership in professional bodies. Since timber construction is seen as so essential to future sustainable, efficient building practices and vital to meeting building targets (as evidenced by the UK government roadmap described above), this link to professional recognition is essential. In addition, training must be provided to those from other industry sectors to help close the skills gap.

To enable this much needed educational and construction delivery transition, the New Model Institute for Technology and Engineering (NMITE), a newly founded (2018) university based in Hereford, England with a focus on engineering and technology, developed courses in response to a sector-defined skills competency framework, the Timber in Construction Skills Action Plan (Timber Development UK, 2023). This framework defines the required technical knowledge and transferable skills that should be embedded in the education of work-ready and multi-disciplinary professionals who can embrace net-zero construction approaches and integrate principles of circularity (Hitt et al., 2023).

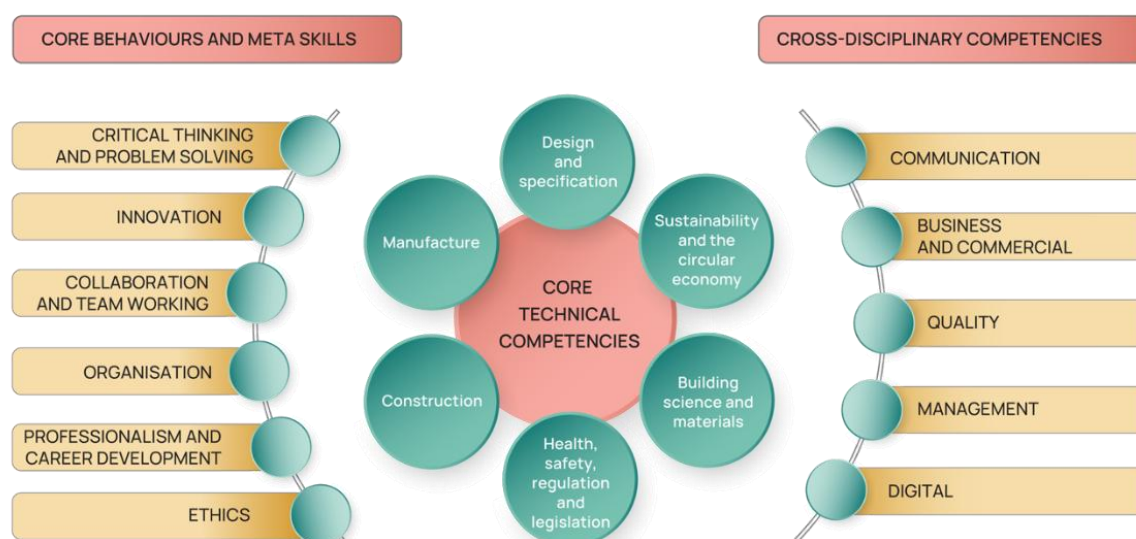


Figure 5.2.2: Skills and competencies outlined in the Timber in Construction Skills Action Plan. Visualisation by L. Kovacova, 2023. Copyright Timber Development UK, adapted with permission, no further use allowed.

The skills framework was the impetus for the development of Timber Technology Engineering and Design (TED), an award-winning series of courses that form the foundation of NMITE's Centre for Advanced Timber Technology's (CATT) educational offerings. The TED courses are an example of widespread collaborative creation across industry and academia to co-develop the course syllabus. The original course structure comprised three distinct topic areas over a 12-week hybrid model delivered by CATT's academic team, hired for their experience in industry as well as in further and higher education. With feedback from students and industry partners, the course was later revised into three separate modules, two delivered online and the third module delivered partially online, with practical skills experience in the CATT workshop. This approach exemplifies educational design that continually redevelops content to meet the changing landscape of construction and adjusting delivery mechanisms for easy uptake by industrial partners.

The online content uses the Canvas Learning Management System, allowing for skills development tracking. Outcomes are outlined according to the Skills Action Plan, and each online learning activity is linked to relevant learning outcomes. Individual quiz questions, for example, can be aligned to specific skills, e.g. in communication, ethics, health and safety, or sustainability, and learner development of those skills is tracked throughout their engagement with the module activities. Skills mastery is then defined through a proficiency rating (4 – exceeds mastery, 3 – mastery, 2 – near mastery, 1 – below mastery, 0 – no evidence), which results from learners achieving certain scores on module learning activities. This can be tracked through a gradebook that the learners can also access, meaning that they can demonstrate their learning in different skill areas to their current or potential employers.

Whereas TED was designed to specifically address timber skills, NMITE's recently started (2025) BSc Construction Management will take a broader view of the construction industry's skills needs. Still, the transferable skills identified in the Timber Skills Framework remain consistent and will be brought into the BSc, using the same mastery tracking method.

Industry partners like those represented in the BSc's Employer Advisory Group (EAG) have been vital to NMITE's educational approach since its inception (Rogers et al., 2021). Its first cycle degree BSc modules also provide an incubation centre for the industry to explore new techniques and methods in a controlled environment. Testing new methods can be costly and potentially damaging to reputations if the resulting process or method creates unintended consequences. By creating collaborative educational approaches with industry-led challenges, students learn to solve problems that also inform future innovations. This highly engaged approach to partnering with industry gives CATT the ability to continually evaluate the relevance of the skills emphasised in its educational offerings.

The development of short courses at NMITE's CATT demonstrates how lessons from industry can be fed into educational offerings and suggests ways in which courses can be steered to meet the building industry's ever-changing landscape through industry engagement. Moving forward, exploring the impact of these programmes on both

individuals and businesses will help derive additional insight about emerging needs. Further research connected with industrial partners to accurately measure current skill levels and identify needed skills is yet another possible approach to prepare workers for the future construction economy. For more information about this case study, we refer to the Centre for Advanced Timber Technology, CATT (NMITE, 2026).

3.3 Case 3: identifying and validating core competencies, essential knowledge, and skills and attributes in nuclear engineering (UNSW)

The third case study presents a systematic, collaborative approach to identifying and prioritising the skills and competencies required for nuclear engineering practice in Australia. The process is based on engagement with industry professionals through workshops, supported by position description analyses and standards-based competency modelling. The findings were translated directly into curriculum design decisions, ensuring alignment between workplace expectations and university education.

The Define Your Discipline (DYD) process was used to develop Australian competency frameworks in environmental engineering, geoscience, and mining engineering (Dowling & Hadgraft, 2011, 2013). These frameworks have been adopted by professional bodies such as Engineers Australia as Stage 1 competencies in these disciplines. Prompted by National Defence priorities and emerging energy security questions, nuclear engineering in Australia is entering a period of growth, and several universities are considering new education programmes. There is also a recognised need to upskill the existing industrial workforce to work in this emerging sector. Thus, there is a clear need for a national competency framework for Australian nuclear engineers.

Given that most practitioners in Australia learn nuclear engineering informally or on the job, it is important to identify the common topics and concepts covered in learning nuclear engineering in the workplace. This research employed the DYD process to lay the foundation for a competency framework for the discipline of nuclear engineering. The overall approach was guided by standard IEEE (Institute for Electrical and Electronics Engineers, a professional engineering institution) Recommended Practice for Defining Competencies (2022).

Data was collected from DYD workshops (Dowling & Hadgraft, 2011, 2013) which had the aim to validate the core competencies required for specific groups of engineers and scientists practicing nuclear engineering in the workplace. Each workshop included a tailored DYD worksheet, developed based on relevant position descriptions (PDs) and customised to reflect the responsibilities of each role. The worksheet contained a comprehensive list of tasks, knowledge areas, skills, and attributes (collectively referred to as KSAs), derived from the PDs. An example of a DYD worksheet is presented in Fig. 5.2.3.

DYD Worksheet		Position Number: 0668	Position Name: Reactor Engineer
Instructions: 1. Read and highlight the Knowledge, Tasks, and Skills that are listed as part of your role. 2. Write and Knowledge, Tasks, and Skills that are missing from the list. 3. Rank the Knowledge, Tasks, and Skills that you highlighted in order of importance. 4. Using your rank number, match the Task to the Knowledge and Skill it requires.			
Knowledge	Task	Skill	
Nuclear Industry & Governance Nuclear Operations & Technology Nuclear Reactor Physics & Engineering Nuclear Safety Quality Assurance & Plant Operations Regulated Environments		Analytical Communication (Written) Communicate (Verbal) Diagnostic Organisation and prioritisation Problem solving Teamwork	

Figure 5.2.3: Example of DYD worksheet utilised to review, validate, and prioritise listed tasks and KSAs (Own Work)

Participants employed at the Australian Nuclear Science and Technology Organisation (ANSTO) were asked to review, validate, and prioritise the listed tasks and KSAs pertinent to their roles, as well as to identify and add any missing elements. Following this, participants were asked to map each task to the corresponding knowledge and skill it required. A gap analysis was conducted between the competencies identified by the staff of eleven roles in the DYD workshop and those baseline competencies derived from the PDs, using the IEEE 1484.20.20-2022 standard model.

A widely used multi-criteria decision making (MCDM) technique named TOPSIS (Hwang & Yoon 1981) was utilised to calculate the relative importance of the tasks and KSAs obtained from the DYD workshops. Following this, hierarchical clustering was performed utilising Ward's method (Ward, 1963), as this method minimises variance within clusters. A hierarchical tree (dendrogram) was constructed as seen in Fig. 5.2.4 and 5.2.5.

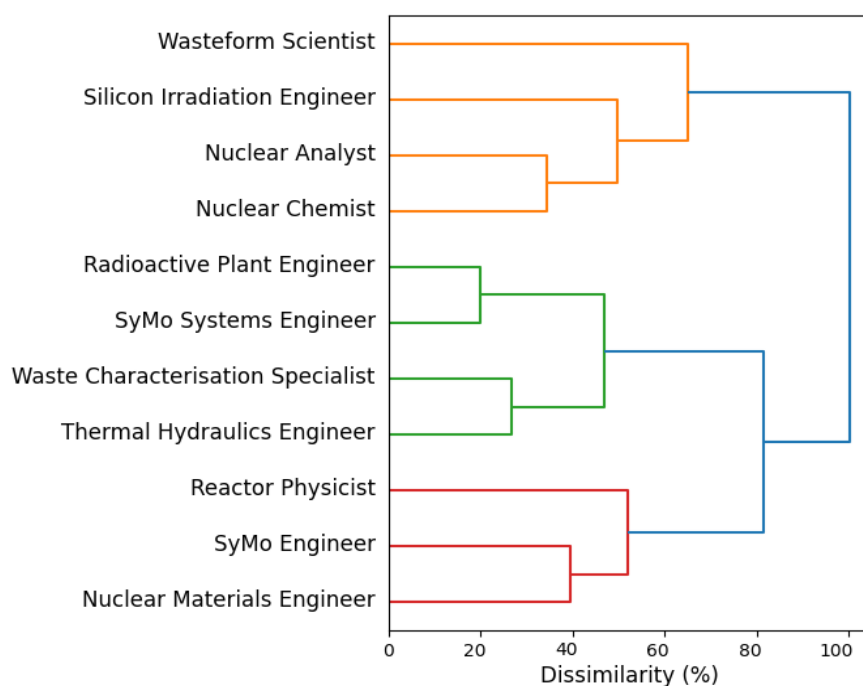


Figure 5.2.4: Roles compared based on technical skills requirement (Own Work)

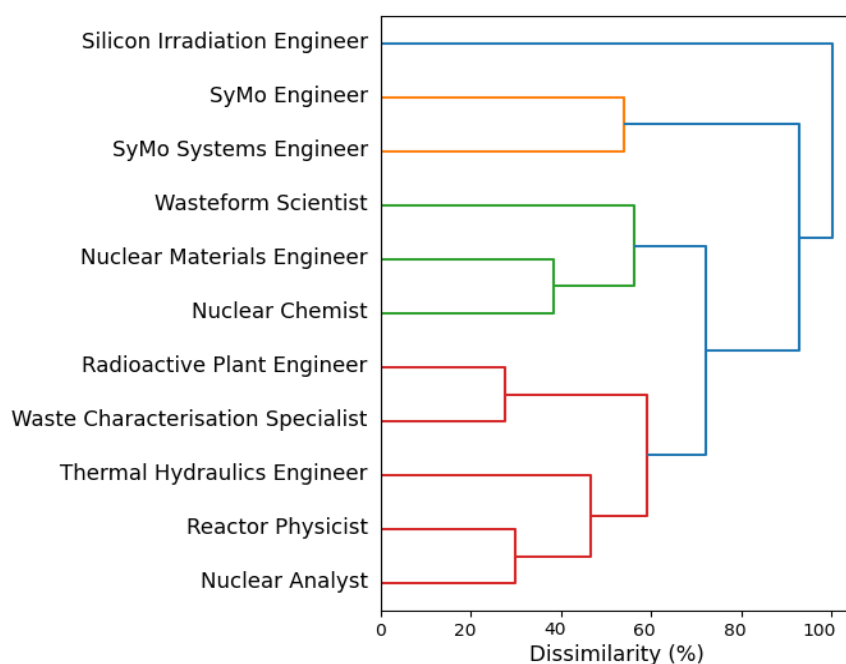


Figure 5.2.5: Roles compared based on non-technical (soft) skills requirement (Own Work)

The dendrogram provides a visual representation of the clustering process, showing the roles that are most similar to each other in terms of technical and non-technical skills. The branches of the dendrogram indicate the roles that were most similar to each other based on the relative importance obtained from the MCDM TOPSIS analysis. The highest-ranked tasks and associated KSAs for all the respondents were identified. Since task importance varied across roles, the top five tasks, knowledge, and skills for each role were prioritised to inform course design in nuclear engineering.

Biclustered heatmaps were generated to visualise the distribution and intensity of skill importance across roles. By clustering both roles and skill domains, the heatmaps reveal groups of roles that require similar competencies and highlight shared skill domains. From a curriculum perspective, these clusters indicate opportunities to design shared core units for roles with overlapping skills and competency requirements, while distinguishing specialised streams where knowledge patterns diverge. From an assessment perspective, the visualisation helps identify which skills and competencies should be assessed collectively within integrated tasks, and which require role-specific evaluation. Together, the dendrograms and heatmaps translate workforce competency data into structured guidance for curriculum architecture, unit sequencing, and targeted assessment design. All roles require up to 50% or more non-technical skills, as illustrated in Fig. 5.2.6. This highlights the importance of embedding non-technical skills in the engineering curriculum.

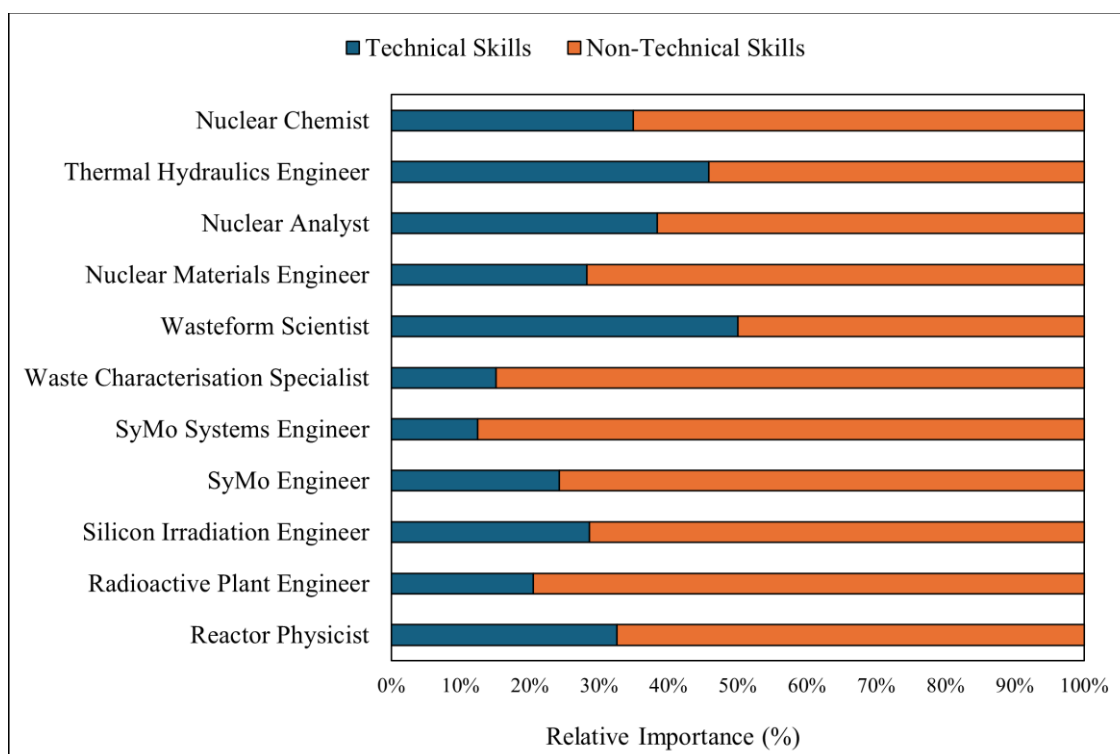


Figure 5.2.6: Technical versus non-technical skills bar chart for a range of roles at ANSTO (Own Work)

The method of evaluating skills and competencies for UNSW nuclear engineering through position description analysis and DYD workshops highlights the value of industry and academic collaboration. The transferable, non-technical skills identified across eleven nuclear science and engineering roles were translated into tangible outcomes in UNSW's course design and delivery, ensuring that it directly reflects workplace needs. This case shows how engineering education can be aligned with the real-world skills needed in a rapidly changing sector. Looking ahead, ongoing engagement with industry and professional bodies will be essential to maintain relevance, while further research will provide evidence needed for tracking skills and competencies alignment and feeding insights back into engineering education development.

For more information on the DYD tools and processes used in Case 3, we invite you to read *The DYD Stakeholder Consultation Process — A User Guide* by Dowling and Hadgraft (2013).

4 Implications for practice

Although the practices presented in the case descriptions above may seem quite different, we can still observe some commonalities. All processes include rather extensive networks of actors and certain level of industry involvement; they are based on a commonly agreed framework or listing of competencies; and they include elements by which the data gathered, and knowledge created in the process is formed into educational actions.

The NMITE and UNSW cases concentrated on specific fields (timber technology engineering and construction, and nuclear engineering), whereas the TEK case looked at the relevance of skills at a general engineering level. In the field-specific processes, the perspective of professionals was obtained by bringing in direct informants from the industry, whereas in the TEK process it was conveyed indirectly via the work experience of the graduates. However, the TEK case illustrates the benefits of a large national academic network, resulting in ample opportunities for benchmarking between different universities and engineering disciplines and degree programmes. As different actors view the purpose of engineering and engineering education differently, it is important that the evaluation of the relevance of transferable competencies and skills acknowledges these different viewpoints; evaluation should aim at a balanced compromise, so that the educational impact of the development work based on the evaluation serves all the stakeholders' needs.

In addition to having a sufficiently large network of actors, the comprehensiveness of the evaluation can be ensured by basing the evaluation on a carefully derived set or framework of skills and competencies. In the NMITE case, an existing Timber in Construction Skills Action Plan served as the framework for the definition of appropriate skills and competencies to be used in the educational programmes (see Fig. 5.2.2). In TEK case, the list of skills and competencies included in the graduate survey had been originally designed in cooperation with TEK and universities and had been monitored and updated yearly with the agreement of the whole network. In the

UNSW case, the competency framework was created following an established DYD process.

From the viewpoint of academic development, getting high-quality and appropriate evaluation of skills relevance is useless unless it is utilised for deriving actionable recommendations, which can then be executed. Although evaluation of relevance may often be an interesting pursuit of knowledge per se and even end up published in academic journals or conferences, the main objective should be the improvement of academic practice, and curriculum development processes should be designed accordingly. In the pursuit of practical gains, systematic procedures for disseminating and utilising the results, like the TEK seminars and workshops and NMITE's continuous course development, are essential. Even if academic publishing is a secondary objective compared to educational development, evaluations that are well designed, effectively implemented, and used to improve practices can also be valuable to those outside the immediate context. Disseminating them effectively is therefore advisable. Useful guidance on how to do this is found in Chapter 5.6. of this handbook.

Rapidly changing work demands and the enormous pace of technological development mean it is essential to ensure that the evaluation of the relevance of skills and competencies stays up to date. For instance, the TEK graduate survey is a continuous process which collects, analyses, disseminates, and utilises information yearly. To keep the process going, a formal structure with clearly defined roles, responsibilities, and resources is needed. In the case of NMITE, we have adopted an internal Programme Enhancement Plan designed to gather timely response to feedback from the Employer Advisory Group, to keep the relevancy current. Processes like these often require an official commitment from the leadership of the organisations involved. When the processes are not running continuously, repeating them when necessary is required. In this case, clear documentation of the procedures enhances effectiveness and saves time and resources.

5 Recommendation for practice

Whether starting a new initiative or building on existing data, practitioners should adopt a systematic approach that will help to ensure the ongoing relevance of transferable skills to their particular context and be willing to change course if feedback suggests it. The key steps we recommend taking include:

- Agree on contextual orientation and determine any relevant educational or industrial policy;
- Review literature for similarly oriented approaches;
- Find and engage industrial, academic, and civic partners;
- Make use of the existing skills and competencies frameworks (see Chapter 1.3 in this handbook);
- Make use of the existing and proven processes for creating skill profiles and/or evaluating their relevance, such as the cases introduced in this chapter;
- Design the processes for producing and using of the results to complement each other (see Table 5.2.1. for ideas about methods and their alignment);

- Produce clear documentation of the processes and keep it up to date;
- Embed continual evaluation and improvement into course design and delivery.

Communication and collaboration among all stakeholders are thus key to evaluating the relevance of transferable skills. Practitioners should be prepared to adopt a mindset that allows them to be prepared to question what and who is not represented in the available data, and how those gaps might be filled. They must also be flexible and adapt as new technologies and skills needs emerge and acknowledge their own need to upskill in order to better prepare tomorrow's workforce.

The three processes for evaluating the relevance of skills and competences which we described above were all based on competency frameworks developed by specific stakeholders for distinct contexts. This is often necessary due to the lack of a universally accepted or applicable framework. However, there is at least one attempt to systematise the research on student perception of transferable competencies and skills, namely the Generic Competence Perceptions Questionnaire (GSPQ) developed by Chan, Zhao and Luk (2017) which has been used to study students' perception of importance (Pinto et al. 2023) as well as students' perception of their competency levels (Chan & Fong 2018). This could serve as a useful starting point for example if you are a degree programme leader who wishes to gauge how your students currently perceive the relevance of transferable skills and competencies.

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AI statement

During the preparation of this work, some authors used Microsoft Copilot for help in formatting the references, and DeepL to check the grammar in the original draft. After using these tools, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

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5.3

How to Evaluate Education Outcomes

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Keywords: *programme evaluation, outcomes-based assessment, professional skills, rubric, student perception, evidence-informed practice*

Engineering programmes increasingly aim to develop graduates who can integrate disciplinary knowledge with transferable competencies such as communication, teamwork, ethical awareness and lifelong learning. To understand whether these outcomes are being achieved (and to improve teaching and curricula), educators need more than individual student assessments: they need systematic evaluation of outcomes at module, programme, and institutional levels. This chapter distinguishes assessment (methods that generate evidence of student performance) from evaluation (the process of interpreting aggregated evidence, together with stakeholder perspectives, to judge quality and inform decisions). Building on outcome-based education and quality assurance practices, we present a practical approach to designing an outcomes evaluation plan. The approach starts by clarifying purposes and evaluation questions, translating outcomes into indicators and performance criteria, and mapping where evidence is generated across the curriculum. It then combines direct and indirect measures to triangulate findings and strengthen interpretations. Finally, the chapter emphasises closing the loop: using results to guide curriculum development, educational policies, and staff development, and documenting continuous improvement for internal and external stakeholders.

1 Introduction

Engineering programmes have undergone a significant paradigm shift since the early 21st century, largely catalysed by the adoption of outcome-based accreditation standards such as the ABET Engineering Criteria 2000. While the integration of technical knowledge with broader professional skills has been a strategic goal for decades, these programmes increasingly prioritize the development of graduates who can seamlessly blend disciplinary expertise with transferable competencies — including communication, teamwork, ethical awareness, and critical thinking. In recent years, this approach has shifted towards managing complexity and sustainability, requiring engineers to possess not only technical skills but also advanced systems thinking to tackle interconnected global problems (Lönngren & Svanström, 2025). This intensified focus is driven by the complex demands of Industry 5.0 and the global urgency for sustainable development, which necessitate an unprecedented capacity for lifelong learning and ethical leadership (International Engineering Alliance, 2021; Muzulon et al., 2025; Sangwan et al., 2022).

However, declaring intended learning outcomes is not enough (Banta & Palomba, 2015). Programmes need credible evidence about whether students are developing these competencies and how learning opportunities across the curriculum contribute to that development (Crawley et al., 2014; Felder & Brent, 2003). Systematic evaluation of educational outcomes supports evidence-informed curriculum design and teaching enhancement, including checking that learning activities and assessment tasks are aligned with the intended outcomes (Biggs & Tang, 2011). It also provides transparency and accountability to stakeholders such as students, employers, professional bodies, and quality assurance agencies (Banta & Palomba, 2015).

In this chapter, ‘assessment’ refers to the methods used to generate evidence of learning (e.g., rubrics for projects, portfolios, peer and self-assessment, surveys, interviews, learning analytics). ‘Evaluation’ refers to the process of interpreting and triangulating that evidence (usually at cohort or programme level) to judge the extent to which outcomes are being achieved and to decide what should be improved. In other words, assessment produces evidence; evaluation turns evidence into decisions and action (Banta & Palomba, 2015; Olds et al., 2005). This distinction between assessment and evaluation reflects established strands in evaluation theory, particularly decision-oriented and use-focused approaches, which emphasise the role of evidence in informing judgement and improvement processes (Christie & Alkin, 2023).

Outcomes evaluation can take place at multiple, connected levels: (1) a teaching or curriculum intervention (e.g., introducing peer feedback to strengthen teamwork); (2) a module; (3) a full programme or curriculum; and (4) an institution or cross-institution initiative. Each level may require different evidence sources, time horizons, and stakeholders, but all benefit from a clear evaluation plan and an explicit ‘closing the loop’ process (Banta & Palomba, 2015; Felder & Brent, 2003).

Across Europe and beyond, outcomes-based approaches are increasingly embedded in internal quality assurance and accreditation processes (Augusti, 2009; Lucena et al., 2008). In this context, evaluation should not be treated as an administrative add-on: it is a mechanism for keeping skills education relevant, equitable, and sustainable over time.

This chapter supports educators and programme leaders by providing a practical framework. Section 2 explains how to use assessment evidence to evaluate programme outcomes and support continuous improvement. Section 3 explains how to design and run an outcomes evaluation plan that turns evidence into curriculum improvement, educational policy decisions, and staff development actions. Section 4 outlines approaches for evaluating specific transferable skills, and Section 5 provides illustrative examples and implementation tips.

2 Using assessment evidence for programme outcomes evaluation

This section is not about assessments and grading practices, but about the systematic use of assessment data to evaluate educational outcomes and improve programmes. Assessment determines whether individual students have met the defined criteria for module passing. In contrast, evaluation interprets aggregated assessment evidence over time to determine the extent to which programme-level education outcomes are being achieved and to inform module contents, curriculum development, quality enhancement, and policy decisions.

2.1 Types of evidence for programme outcomes evaluation

Evaluating educational outcomes requires drawing on multiple complementary sources of evidence, as no single measure is sufficient to determine whether intended outcomes, such as transferable skills and competencies, are being achieved consistently across a cohort. Effective evaluation, therefore, depends on the systematic collection, aggregation, and interpretation of structured data. There are basically two types of evidence required for evaluating education outcomes: direct evidence and indirect evidence — which often generate a combination of quantitative and qualitative data.

Direct evidence of outcome attainment. Student work that is clearly aligned with specific educational outcomes serves as direct evidence. Examples of such evidence include the writing and presentation of final-year dissertations, capstone projects, laboratory assignments, design reports, and weekly project progress presentations. When these artefacts are evaluated against appropriate performance rubrics or criteria, they provide measurable indicators (often in the form of quantitative data) of whether the educational outcomes and module objectives are achieved. The importance of these artefacts for assessing students lies not in individual grades but in overall performance trends. For instance, rubric data collected from several students over time can highlight consistent weaknesses in critical thinking or problem solving, as well as recurring strengths in teamwork or communication. These insights can inform curriculum improvements or changes in teaching methods. The rationale for using different evidence measures is their proximity to authentic performance. Direct

evidence artefacts and data enable programme teams to evaluate whether students can demonstrate the intended transferable skills and competencies in realistic contexts. In this context, Sandoval (2014) argues that participant artifacts are essential because they serve as 'proxies' for learning processes. These artifacts indicate the extent to which learners are engaged in the specific activity and thinking hypothesized to be significant for achieving the desired outcomes.

Indirect evidence and perception-based measures. Surveys and feedback from students, alumni, instructors, and employers serve as indirect indicators of educational quality, providing insight into learners' perceptions of their growth and readiness. These artefacts, while they do not directly demonstrate competencies and transferable skills, offer valuable qualitative insights into how programme education outcomes are perceived, experienced, and valued by different stakeholders. At the programme level, these artefacts also serve important evaluative functions, as they can reveal perceived gaps in the curriculum and teaching approaches, track students' development and confidence in transferable skills, and enable comparisons between internal performance patterns and external expectations. It is important to note that indirect evidence must be interpreted with care, as response bias, cultural differences, and varying stakeholder expectations can influence it. For this reason, indirect indicators should supplement, rather than replace, direct evidence of student learning and performance. The rationale for integrating indirect evidence is that programme quality encompasses not only demonstrable performance at the programme level, but also stakeholder perceptions of satisfaction, the degree to which the curriculum supports employability, and its alignment with contemporary professional practice. According to recent studies, perception surveys provide more information when interpreted alongside direct evidence of learning. Without this cross-referencing of data, individual instruments often do not offer sufficient validity for programme evaluation (Osipovskaya et al., 2024).

The distinction between assessment and evaluation rests on the aggregation and interpretation of evidence. Module-level data must be systematically aligned with programme-level outcomes through processes such as consolidating rubric scores, examining longitudinal trends, comparing cohorts, and identifying acceptable attainment thresholds. Analytical tools support this work by revealing patterns that inform evidence-based judgement. Triangulating quantitative and qualitative data from direct, indirect, and institutional data strengthens the credibility of conclusions, while structured analysis ensures decisions are grounded in coherent evidence rather than isolated impressions. To put this distinction into practice, institutions use frameworks based on defined indicators and strategic assessments. This provides reliable and scalable evidence of student performance at programme level (Mahalingam, 2026).

Furthermore, evidence (both direct and indirect) on educational outcomes is valuable only when it is part of a clear evaluation framework in which data are analysed against predefined criteria and directly inform programme decisions. This systematic approach aligns with the technique of 'conjecture mapping', which Sandoval (2014) defines as

a means of specifying theoretically salient features of a learning environment, mapping how they are predicted to work together to produce desired outcomes. Such a framework provides an 'argumentative grammar', the logic that guides a method and supports reasoning about its data, clarifying how practical improvement and theoretical refinement occur concurrently. This includes assessing whether desired outcomes are met, identifying gaps or overlaps in the curriculum, guiding targeted actions like curriculum redesign or staff training, and tracking the results of these actions. In this broader evaluation process, assessment tools serve not only as methods for measuring learning but also as sources of practical insights that help to continuously improve the program.

Integrating direct and indirect data and analysing them within a clear framework provides a coherent understanding of educational quality and informs curricular decisions that support continuous improvement and alignment with evolving professional demands. This systematic classification of evidence ensures that the evaluation is grounded in a logical structure, rather than isolated observations, providing what is known as an argumentative grammar for the assessment process.

The identification and analysis of the different sources of evidence provide the foundation for determining what information can credibly support judgements about the achievement of learning outcomes. However, having evidence is not enough on its own: a structured process is required to decide what will be evaluated, how the evidence will be interpreted, and how conclusions will translate into concrete improvement actions. Section 3 addresses this need by presenting a practical framework for designing and implementing an outcomes evaluation plan that turns collected evidence into coherent decisions at module, programme, or institutional level.

3 Practical solutions for an effective outcomes evaluation plan

Once transferable skills and other intended learning outcomes are embedded in modules and curricula, educators and programme leaders need a structured way to determine whether those outcomes are being achieved, for whom, and under what conditions. An outcomes evaluation plan describes (1) what will be evaluated; (2) which evidence will be used; (3) how findings will be interpreted; and (4) how improvement actions will be agreed upon, implemented, documented, and reviewed.

3.1 Principles for a credible and useful outcomes evaluation

Effective outcomes evaluation is 'fit for purpose', that is, it is designed around decisions that need to be made, collects only evidence that will be used, and makes explicit how evidence will be turned into improvements. The following principles help ensure that conclusions are credible and that the process is sustainable.

Start with identifying intended users and decisions to be made. Clarify who will use the findings (e.g., teaching teams, programme committees, students, employers, quality assurance or accreditation reviewers) and what decisions the evaluation needs to inform (e.g., curriculum redesign, staff development priorities, resourcing).

- *Prioritise validity of inferences.* Use evidence that genuinely represents the intended outcomes (especially complex transferable skills), ensuring that the evidence maps directly to the intended construct (e.g., content-based evidence) and avoid over-interpreting single tasks or single cohorts.
- *Support consistency and reliability.* Where human judgement is involved (e.g., rubric scoring), use assessor calibration, moderation, and stable scoring guidance so that trends across cohorts can be interpreted with confidence.
- *Build in triangulation.* Combine multiple sources and perspectives (direct and indirect, quantitative and qualitative) so that conclusions do not rely on a single measure.
- *Attend to fairness and equity.* Check whether evidence generation or interpretation disadvantages particular student groups; where possible, review patterns using disaggregated data and consider contextual explanations before acting.
- *Be transparent and proportionate.* Make outcomes, criteria, data sources, and limitations visible to stakeholders, and design a process that is feasible within available time and resources (e.g., sampling, rotating outcomes on a multi-year cycle, reusing existing assessment data).

3.2 Building the evaluation plan: a practical workflow

The workflow below can be adapted to different contexts (single module, full programme, or institution-wide initiative). It is deliberately framed around outcomes evaluation rather than the design of individual assessment tasks.

1. *Define the scope and evaluation questions.* Specify what level is being evaluated (module, programme, institution), which outcomes are in scope, and what decisions the evaluation should enable. Keep the initial set of questions small (e.g., two to four questions) and relevant to the decisions to be made.
2. *Translate outcomes into indicators and success criteria.* For each outcome, define a small number of observable indicators and set an acceptable achievement (performance criteria or targets). For transferable skills, indicators often need to be context-specific (e.g., teamwork in design projects versus teamwork in laboratories).
3. *Map where evidence is generated.* Use a curriculum map (or evidence map) to identify where each outcome is introduced, developed, and demonstrated, and to select a few high-value evidence points (often called signature assessments) that will be used for evaluation.
4. *Select evidence sources and a sampling strategy.* For each outcome, choose two or three complementary sources (e.g., rubric-rated performance in authentic tasks plus a student survey and/or supervisor feedback). Decide which cohorts will be included, how often evidence will be collected, and whether sampling is needed to keep the workload manageable.
5. *Plan data management and analysis.* Assign responsibilities (who collects, anonymises, analyses), specify timelines, and define how evidence will be stored securely. Predefine simple analysis approaches (e.g., cohort-level

distributions, trends over time, subgroup patterns, thematic analysis of qualitative comments).

6. *Aggregate, triangulate, and interpret.* Bring evidence together at the cohort or programme level and check for convergence or plausible reasons for divergence across sources. Interpretation should include uncertainty: what the evidence supports strongly, and what requires caution or further data.
7. *Decide, act, and 'close the loop'.* Hold a structured evaluation (sense making) meeting to agree conclusions and actions. Translate conclusions into a time-bound improvement plan (curriculum changes, assessment policy adjustments, learning support, staff development), assign owners, and document what was changed and why (Felder & Brent, 2003).
8. *Review impact and improve the evaluation process itself.* In the next cycle, check whether actions corresponded to improvements in the targeted outcomes, and refine indicators, evidence points, or analysis methods where needed (meta-evaluation) (Banta & Palomba, 2015).

3.3 Minimum documentation to support continuous improvement

To keep outcomes evaluation manageable, it helps to maintain a small set of living documents that can be updated each cycle. A typical minimum set includes:

- An outcomes evidence map (matrix) showing which modules and activities provide evaluative evidence for each outcome;
- Definitions of indicators, performance criteria or targets, and any rubrics used for programme-level judgements;
- An evidence calendar (what is collected, from whom, and when);
- An annual or cyclical evaluation summary that records the evidence reviewed, conclusions reached, limitations, and agreed actions;
- An improvement log tracking actions, owners, timelines, and follow-up evidence ('closing the loop' documentation).

Once an evaluation plan is established and a systematic process for turning evidence into curricular and organisational improvements is in place, a further challenge arises: evaluating the transferable competencies that are essential in engineering education. These competencies — such as problem solving, critical thinking, design, teamwork, and communication — require tailored methods and context-appropriate approaches due to their complexity.

4 Examples

The following examples illustrate how the principles outlined in the previous sections can be applied in real educational contexts. Each example highlights different dimensions of outcomes evaluation, such as the use of authentic assessment evidence, triangulation across data sources, faculty calibration, or the integration of evaluation results into programme-level decisions. Together, these examples demonstrate how structured evaluation processes operate in diverse institutional settings and provide practical insights that reinforce and complement the conceptual framework developed in Sections 2 and 3. Examples 1 and 2 operate primarily at the

module level, demonstrating how systematic assessment of transferable skills generates the evidence base that feeds into programme-level quality assurance cycles and improvement decisions. Example 3 illustrates evaluation at the full programme level. For more information on how to teach and assess these competencies, we refer you to the relevant chapters in Part 2 and 3 of this handbook.

4.1 Evaluation of outcome-based assessment through project-based learning in electronics engineering at USTP

The University of Science and Technology of Southern Philippines (USTP) is a public state university located in Mindanao, Philippines, offering accredited engineering programmes aligned with national and regional quality assurance frameworks. Like many institutions operating within outcome-based education systems, USTP has progressively integrated programme-level evaluation mechanisms to support continuous quality improvement and international benchmarking.

At the USTP, the College of Engineering implemented a refined outcomes-based education (OBE) framework through a project-based learning (PBL) approach in its Electronics Engineering capstone design module. This initiative aimed to enhance the assessment of both technical and transferable skills such as communication, problem solving, and teamwork.

Context and implementation

The module required student teams to design, prototype, and test Internet of Things (IoT) solutions addressing local community needs (e.g., water-level detection for flood-prone areas, smart energy meters for small enterprises). Projects were aligned with ABET and the Philippines Commission on Higher Education (CHED) engineering outcomes, with particular focus on, problem solving, design and experimentation, communication, ethics, and lifelong learning

Table 5.3.1: Assessment tools and techniques used

<i>Tool/technique</i>	<i>Purpose</i>	<i>Frequency</i>	<i>Platform</i>
<i>Rubrics (holistic and analytic)</i>	Evaluate design quality, innovation, documentation, and teamwork	Per milestone	Google Docs/Canvas LMS
<i>Peer and self-evaluation</i>	Reflect on team contributions and learning	Biweekly	Microsoft Forms
<i>Faculty feedback loop</i>	Weekly design check-ins and troubleshooting	Weekly	In person and online
<i>Formative surveys</i>	Capture ongoing learning challenges	Midterm and finals	Microsoft Forms
<i>Capstone pitch scoring</i>	Real-time evaluation during Demo Day	End of module	Panel (academic and industry)

Rubrics were structured on a four-level scale (Beginning, Developing, Proficient, Advanced), with weighted criteria assigned to technical accuracy (40%), design innovation (25%), communication clarity (20%), and teamwork and process documentation (15%). Faculty calibration sessions were conducted prior to milestone grading to improve inter-rater reliability. Peer assessments contributed 10% of the teamwork component to promote accountability.

Quantitative outcomes

- 80% of teams improved their design scores by at least one rubric level (e.g., from Developing to Proficient) between milestone 1 and Demo Day.
- 94% of students rated the feedback and peer assessment system as 'clear' or 'very clear', based on end-of-semester surveys (n=72).
- 75% of students identified teamwork as their most improved skill through reflective self-assessments.
- Faculty scoring variance reduced by 28% over two terms after rubric calibration and peer norming.

What worked

- Scaffolded assessments, in which rubrics were layered across phases (ideation → prototyping → deployment) helped reinforce key outcomes without overwhelming students.
- Peer and self-assessment empowered students to take ownership and reflect on their roles, improving engagement and group accountability.
- Feedback loops with weekly consultations and digital feedback tools shortened the feedback cycle, allowing for immediate iteration.

What we learned

- Rubric clarity is key. Language must be aligned with student comprehension levels; visual anchors (e.g., sample outputs) helped a lot.
- Tracking progression matters. Comparing early-stage and final outputs gave students a tangible sense of growth.
- Team dynamics must be managed. Some high-performing groups still experienced internal conflict; proactive monitoring helped address this early.

Institutional alignment

This module design aligned with USTP's academic KPIs and supported programme-level quality assurance processes. In the Philippine context, this included compliance with regional accreditation frameworks such as AUN-QA, the ASEAN University Network Quality Assurance (ASEAN University Network, n.d.) and national accreditation bodies. Comparable processes exist within the European Higher Education Area under the Bologna Process and ESG quality standards. The aggregated rubric data, peer assessment records, and survey results from this capstone module serve as direct and indirect evidence inputs into USTP's annual programme evaluation cycle, informing decisions on curriculum sequencing, faculty development priorities, and learning support provision at the programme level.

4.2 Evaluation of Simulation-supported reflective assessment in process engineering education

At the University of North Dakota, a graduate-level chemical engineering module integrated reflective practice with Aspen Plus simulations to evaluate students' communication and critical thinking skills. As part of a midterm assignment, students designed a sustainable ammonia production process using green hydrogen. The project required them to consider environmental impacts, energy balances, and cost efficiency, bridging engineering technical skills with sustainable systems thinking.

Quantitative outcomes

- 85% of students showed measurable improvement in their communication skills and ability to justify engineering decisions based on rubrics.
- 78% of students demonstrated greater self-awareness and critical reflection in their journal entries.
- Peer evaluations highlighted and helped address communication gaps within student teams.

What worked

- Combining simulation tasks with reflective journaling fostered deeper learning and higher-order thinking skills.
- Structured feedback loops, both formative and summative, supported continuous improvement throughout the semester.
- Including multimodal communication (written reports, presentations, journals) engaged diverse learners and built confidence in expressing technical ideas.

Table 5.3.2: Assessment tools and techniques used

<i>Tool/technique</i>	<i>Purpose</i>	<i>Frequency</i>	
<i>Simulation reports</i>	Assess technical understanding and optimisation decisions	Midterm and final	Aspen Plus, PowerPoint
<i>Reflective journals</i>	Capture reasoning behind choices and group dynamics	Biweekly	Google Docs
<i>Oral presentations</i>	Demonstrate and defend design choices	End of module	In-person and online
<i>Peer evaluation</i>	Assess communication and contribution to teamwork	End of module	In-person and online

What we learned

- Providing clear rubrics and explicit guidance early is essential for supporting students in reflective and communication tasks.
- Students benefit from early exposure to professional expectations for technical communication and justification of design choices.

- Incorporating analytical tools such as simulations alongside reflective practice strengthens transferable skills for professional engineering work.

Institutional alignment

This practice supports undergraduate and graduate programme-level outcomes on critical thinking and communication. Lessons from this case have been included in departmental quality assurance reviews, leading to curriculum updates with a stronger focus on communication, reflective practice, and industry relevance. The triangulated evidence generated through simulation reports, reflective journals, oral presentations, and peer evaluations has been used as direct and indirect input for programme-level review meetings, helping faculty identify where communication and critical thinking outcomes need stronger scaffolding across the degree sequence.

4.3 A programme-level outcomes evaluation approach: EDINSOST (Spain)

Sustainability is increasingly treated as a transversal engineering competency, closely connected to professional judgement, ethics, systems thinking, and design decision making. Because sustainability is developed across multiple subjects (rather than in a single module), it is particularly well suited to programme-level outcomes evaluation: the goal is not to score individual students, but to determine where, how, and how consistently sustainability-related learning outcomes are embedded in the curriculum, and whether students perceive that they are actually achieving them.

The EDINSOST initiative, a cross-university Spanish research project named "*Education and Social Innovation for Sustainability*", provides a structured and operational model for this purpose. It translates sustainability into an explicit Sustainability Competency Map (SCM), in which the competence is decomposed into competency units and specific learning outcomes, organised across progressive domain levels. This mapping offers a clear reference of expected graduate capabilities and serves as a backbone for both curriculum alignment and evaluation (Sanchez-Carracedo et al., 2021b, 2022). The learning outcomes in the SCM are classified using a three-level domain taxonomy based on a simplified Miller's pyramid, i.e., a framework created by George Miller in 1990 that outlines progressive levels of professional capability, commonly used in medical and healthcare education, (Miller, 1990): Knowing (level 1), which refers to theoretical learning; Knowing How (level 2), which involves integration and development in specific situations; and Demonstrating + Doing (level 3), which is linked to showing the competency in action and the possibility of transferring it to professional practice. This structured hierarchy allows the SCM to be easily embedded into the degree curriculum by assigning specific domain levels to different subjects along the competency itinerary.

From an outcomes evaluation perspective, EDINSOST combines multiple complementary data collection and analyses processes to construct a robust programme-level picture:

Curriculum 'presence' mapping (intended/enacted curriculum). a presence map is produced by identifying which subjects develop which sustainability learning outcomes. The approach can use documentary analysis (e.g., subject guides) and/or

faculty input. To ensure practical reliability, the construction of these presence maps follows a two-step methodology: first, faculty members complete a diagnostic survey; second, experts in education for sustainable development (ESD) conduct semi-structured interviews with those professors. This expert-led intervention is critical to unify reporting criteria across different departments and to mitigate the Dunning-Kruger-effect, where instructors less familiar with ESD may inadvertently overestimate the depth to which sustainability is addressed in their classroom activities.

External referencing to the SDGs (accountability and coherence). EDINSOST also illustrates how to connect programme outcomes to wider societal frameworks. A correspondence matrix can be developed to map programme sustainability learning outcomes to the SDGs (and associated learning objectives), helping programme teams see which SDGs are already supported, where adaptation is needed for engineering contexts, and where gaps remain.

Triangulation with student evidence (experienced/learned curriculum). to evaluate whether the curriculum embedding translates into student learning, EDINSOST proposes using a student survey to capture students' perceived achievement of the sustainability learning outcomes. This assessment of the 'learned curriculum' is conducted through a validated 34-item Engineering Sustainability Questionnaire (ESQ). Students respond to statements using a four-point Likert scale, which enables a pre-post analysis. By comparing the perceived learning of first-year students against those completing their bachelor thesis, programme teams can quantify the relative learning increase across each of four sustainability competencies, holistic, environmental, social, and economic (Sanchez-Carracedo et al., 2021a, 2021c).

This approach supports continuous improvement because the outputs are directly actionable: they identify strengths, weaknesses, and inconsistencies across the programme and across institutions. For example, EDINSOST-related analysis has been used to examine how sustainability is unevenly present across degree programmes and universities, demonstrating how an outcomes evaluation lens can surface curricular disparities that are not visible from single-module assessments alone.

Comparing student perceptions with the presence map can reveal 'alignment gaps' (e.g., outcomes that staff believe are covered but students do not recognise as learned). These findings are directly actionable: they guide the design of targeted faculty training courses and the collection of open educational resources to help teachers embed specific missing learning outcomes into their subjects. Thus, the evaluation plan ceases to be a mere administrative report and becomes a catalyst for curriculum redesign.

As a practical note, because presence maps primarily reflect the intended and enacted curriculum (according to documents and staff reporting) and perception surveys capture indirect evidence, programme teams can strengthen conclusions further by adding direct evidence from selected assessment artefacts (e.g., capstone design rubrics or project portfolios) aggregated at cohort level, especially when high-stakes 'closing the loop' decisions are required.

5 Final remarks

Outcomes evaluation is more than a technical process — it is a mechanism through which institutions learn about themselves. Across the cases and methods described in this chapter, a common message emerges: when evidence is systematically collected, interpreted, and connected to clear decisions, it becomes an engine for meaningful educational change. Programme teams can move from isolated module-level assessments to coherent, programme-wide conversations about what students are truly learning, under which conditions, and with what levels of equity and consistency.

Sustained improvement requires institutional commitment. This includes ensuring time for faculty calibration, supporting data management infrastructures, and recognising evaluation work as part of academic practice. When these enabling conditions are in place, outcomes evaluation strengthens the alignment between curriculum design, teaching practices, and evolving professional expectations.

Looking ahead, engineering programmes face growing demands related to digitalisation, sustainability, global collaboration, and ethical responsibility. These demands cannot be addressed through assessment alone; they require robust evaluation systems capable of integrating direct evidence of performance, stakeholder perspectives, longitudinal data, and contextual interpretation. Embedding such systems across curricula supports transparency, enhances student agency, and builds trust with accreditation bodies and society at large.

Ultimately, evaluation should be understood not as compliance, but as an opportunity: a cyclical process that encourages reflection, fosters innovation, and ensures that engineering education remains relevant, equitable, and future-ready.

Guidelines for transfer to other contexts

While the examples are situated in specific institutional settings, several transferable principles emerge. First, clarify the object of evaluation (skill, outcome, intervention, programme, or institution) before selecting tools. Second, combine direct and indirect measures to strengthen validity and avoid over-reliance on self-report data. Third, calibrate assessment criteria among faculty to enhance reliability and fairness. Fourth, embed feedback loops so that evaluation results inform curriculum decisions rather than remain descriptive reports. Finally, ensure alignment between evaluation data, accreditation requirements, and institutional quality assurance processes to promote sustainable implementation. These principles are adaptable across disciplinary, institutional, and national contexts, provided they are adjusted to local governance structures, resource constraints, and stakeholder expectations.

Resources and Further reading

In addition to the literature referenced in this chapter, we also suggest Borrego et al. (2009), Borrego and Henderson (2014), Falchikov and Goldfinch (2000), Kane (2013), Lang et al. (2022), Messick (1995), Patton (2017), and Pellegrino et al (2014) to deepen your knowledge on evaluating using assessment outcomes.

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5.4

Evaluating Interventions That Develop Transferable Competencies and Skills

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This chapter presents practical guidelines for educators to evaluate educational interventions designed to develop engineering students' transferable competencies and skills. The guidelines can be used when implementing new initiatives at the module or programme level, as well as documenting impact for your promotion dossier. Evaluation should be seen as an integral part of improving teaching and learning because documenting effective educational practices enables them to be appreciated and shared, and to identify points for improvement that fall short of your desired teaching goals. We provide a semi-sequential eight-step guide for articulating evaluation goals, identifying the intervention and skills to be evaluated, selecting methodologies and evaluation tools, and finally acting on the results of the evaluation. Additionally, this chapter offers criteria for assessing the quality of the evaluation itself to ensure the validity, reliability, and credibility of findings. Overall, the chapter will introduce you to tools to design evaluations to inform pedagogical decision making and strengthen the impact of interventions that develop transferable competencies and skills.

1 Introducing interventions for developing transferable competencies and skills

Educational interventions aimed at developing students' transferable competencies and skills, such as communication, teamwork, or critical thinking, are a key outcome for any well-designed engineering programme. This makes it vital to assess how effectively our teaching and educational interventions contribute to this critical aspect of engineering graduates' competence. Yet, many educators face a familiar question: how do we know whether our interventions are actually working? Evaluation is not just a bureaucratic requirement, but a cornerstone for understanding the impact of interventions, improving educational practices, identifying areas for refinement, and guiding future action (Rossi et al., 2019). It helps us move beyond relying on personal experience and intuition, toward methods proven effective through research. This process is inherently iterative and relies on feedback loops to improve or scale promising practices, ensuring that interventions genuinely achieve their intended outcomes.

At the level of individual modules, evaluation helps educators refine learning activities and assessment practices. At the programme level, it supports educators to build coherence across modules and alignment with accreditation requirements. For educators with responsibilities at the level of a programme, evaluation findings can inform strategic priorities and resource allocation. Across these levels, evaluation can address different kinds of outcomes, from student responses to longer-term behavioural and organisational impact, as reflected in models such as Kirkpatrick's (2016) evaluation framework, which we will explain in the next section.

We define an educational intervention as any modification to a programme, module, or instructional setting that has an impact on learning outcomes. Examples are the addition of a short workshop on time management to a project course, revision of the grading criteria for an internship, or inviting an expert from industry to co-teach. Depending on its scale and scope, some evaluations may be described as programme evaluations when they span multiple modules or student cohorts. Whatever the scale, educators need timely feedback to refine intervention strategies and improve learning. An evaluation seeks to "*describe and explain experiences of students and educators and to make judgements and [interpret] their effectiveness*" (Edwards, 1991, p. 13); that is, an evaluation involves both collecting relevant observations and making pedagogical decisions based on their analysis.

Understanding the nature of transferable competencies and skills is also key to their effective evaluation. Unlike purely conceptual knowledge, transferable skills encompass the contextual implementation of emotional, cognitive, and often practical domains. Their development is supported by educational experiences that provide opportunities for deliberate practice, explicit focus on transfer to new contexts, and consistent, actionable feedback. Educational interventions for developing engineering students' transferable skills vary in their scope, duration, and underlying design. Considering the different scales of educational interventions is useful for both designing effective interventions and selecting appropriate evaluation methodologies.

We can broadly categorise interventions by their temporal dimension and systemic nature as shown in Table 5.4.1.

Table 5.4.1: Examples of interventions for developing students' transferable competencies and skills, organised by temporal scale and systemic nature

<i>Temporal scale (duration) →</i>	<i>Short-term, focused activities (hours to days)</i>	<i>Medium-term engagements (week to a semester)</i>	<i>Long term</i>
<i>Systemic nature</i> ↓			
<i>Individual and module-level changes; affect individual students or module deliveries</i>	Targeted workshops, modules, or active-learning activities like those from 3T Play (Isaac & de Lima, 2024).	Structured mentoring sessions, dedicated project work within modules, or formal internships.	Changes in instructor profiles (e.g., industry professionals as co-educators).
<i>Programmatic and institutional changes; broader interventions reshaping the educational experience</i>	Funding large-scale interdisciplinary student-run projects (e.g., iGEM, hyperloop, or solar car or boat competitions).	Curriculum modifications, e.g., structure of internships across curricula, introduction of new cross-departmental degree programmes, integrating makerspaces or other external collaboration into modules	Curriculum redesign: real-client projects, shifting internships from industry to civil society and social agencies

Given the diversity of educational interventions that develop transferable competencies and skills, it can be challenging to determine appropriate ways to conduct relevant evaluations. For other approaches to evaluation and research of transferable skills and competences we refer you to Chapter 5.1 and for more on meaningful educational change we refer to Fullan (2007).

This chapter is intended to give you, the educator, practical guidance on how to both design and interpret an evaluation of interventions targeting students' transferable competencies and skills. We briefly review the design of educational interventions that can facilitate their development. We argue that the evaluation of such interventions should inform their very design, allowing for greater coherence between conceptual understandings of skill development and the implementation of educational interventions. We will continue with a balance of practical considerations and

conceptual framing to prompt you to reflect on the motivations for conducting evaluations, to design and conduct relevant evaluations, and to interpret and benefit from the results of evaluations to improve your interventions for teaching transferable competencies and skills to engineering students

2 The context of evaluating interventions that develop transferable competencies and skills

When evaluating interventions for developing engineering students' transferable skills, it is important to consider why you want to do the evaluation and what its possible consequences may be. Besides the educational aims the intervention, it is important to note that other considerations may shape the evaluation, such as your own personal motivation (e.g., preparing a tenure application or compliance with funding requirements), the needs of any other stakeholders (e.g., department chair, future students, funding agency), and the potential implications of the findings. Given this, it is helpful to start by clearly defining the core question you want your evaluation to answer.

Evaluation also plays a key role in aligning your educational interventions with institutional goals and strategic objectives (Pohlenz, 2022), such as student success and accreditation compliance. Evaluation findings can influence resource allocation, funding, and sustained support. Rigorous evaluation can significantly boost eligibility for grants and funding by demonstrating tangible success, such as increased student retention.

Creating evaluations inherently involves subjectivity and bias, as they are shaped by the evaluator's role, context, and perspectives. Recognising these inherent judgements is essential, as they can influence how findings are interpreted and utilised. One significant example of this is reporting bias, where authors may be inclined to self-censor results or decide not to publish certain works (Pigott et al., 2013). This bias often leads to a disproportionate publication of positive results that indicate the success of an intervention, creating a skewed distribution of research knowledge and a potentially misleading impression from the literature (Dawson & Dawson, 2018).

The evaluation process can provide insight into how and why an intervention works, or conversely, why it might fail. Effective interventions for developing transferable competencies and skills are built on a clear understanding of their intended learning outcomes and the pedagogical conditions appropriate to realise these outcomes. This means an evaluation should start with a clear statement of the learning objectives you are aiming for, how your activities are designed to support those outcomes, and how you will assess whether students have achieved them.

Considering these key ideas about the purpose of evaluation, the nature of interventions, and the need to understand how an intervention impacts learners, we turn our attention to the practicalities of how to evaluate interventions for transferable skills. We will introduce conceptual frameworks and present some guidelines, illustrated through concrete examples to highlight common pitfalls.

Evaluation frameworks such as Kirkpatrick and Kirkpatrick's (2016) can help educators clarify whether they are primarily interested in students' experiences (reaction — level 1), learning (level 2), behaviour change (level 3), or broader impact (results — level 4) of the module. These four levels offer a systematic approach to understanding effectiveness of programmes and modules. The two most accessible levels of this model are *reaction*, which seeks to capture participants' impressions and experiences, and *learning*, which involves assessing their acquired knowledge and skills. Taking the example of transferable competencies and skills for a constructive team climate that includes psychological safety, the *reaction* level could capture if students appreciated an educational intervention (e.g., I liked, I saw value in, I preferred, etc.). The *learning* level measures if the intervention increased what students knew (i.e., assessing knowledge gain) about constructive team climate. The level of *behaviour* could document what participants did to support psychological safety in their project teams. The *results* level documents the impact of these new behaviours on participants' other activities and accomplishments, such as the quality of students' project work or sense of team belonging improved.

Designing evaluations at Kirkpatrick levels 3 and 4 is considerably more complex due to the extended time frames and higher resource requirements. However, these upper levels typically align more closely with the desired impacts for teaching interventions. It is therefore encouraging to note that capturing students' intention to use course material serves as a robust indicator of their future use of course material (Alliger et al., 1997). Indeed, Alliger and colleagues found that students stating that course material was useful to them was a better predictor of them using it (level 3) than direct measures of their learning (level 2).

Complementing this, Brookfield's (1995) framework for reflective practice helps educators interpret evaluation evidence by deliberately incorporating multiple perspectives (lenses): the educator's own experiences, student feedback, colleagues' insights, and the theoretical lens of scholarly literature. A robust evaluation approach can assist educators to engage productively with all lenses, particularly that of scholarly literature which is less familiar to them.

For example, module evaluation questionnaires frequently used in higher education give us insight into student perspectives (both a Brookfield lens and an example of Kirkpatrick and Kirkpatrick's level 1). While valuable, the utility of student feedback can be obscured by poorly constructed questionnaires that are, for example, designed for lecture modules rather than project-based modules, with questions that focus too much on educator activities. Another, perhaps larger issue, is that the student requests are often incorrectly interpreted as sound pedagogical recommendations. Brookfield's approach requires that student opinion questionnaires be digested and analysed from multiple perspectives, including literature. For example, students may state that they would prefer a short lecture on the theory of psychology safety without an application activity. Analysing this student feedback from a learning sciences perspective reminds us that skill development is improved by low-stakes application activities with immediate feedback, so a more constructive response could be preparing students for

the application activity by informing them about the mechanisms of skill development. Consider discussing student feedback with an education expert, as this has been shown to improve teaching (Marsch & Roche, 1993). The challenge of more integrated approaches to evaluation is that they take time, expertise, and coordination. We propose some practical guidelines to accompany you through the conceptualisation, development, and implementation of a coherent evaluation.

3 Approaches to evaluating interventions in skills education

3.1 A practical overview of how to evaluate interventions that develop transferable competencies and skills

This section provides practical recommendations for evaluating interventions that develop transferable competencies and skills. As the approach and methods should be informed by your goals and context, our recommendations start with clarifying the goal of your evaluation. Fig. 5.4.1 provides a semi-sequential series of steps for preparing an evaluation of an intervention that teaches transferable skills. As ever, some recursive revision is likely as your project advances. When the evaluation is designed ahead of time, you can integrate the evaluation into the intervention itself, taking advantage of moments when you are already interacting with your target group.

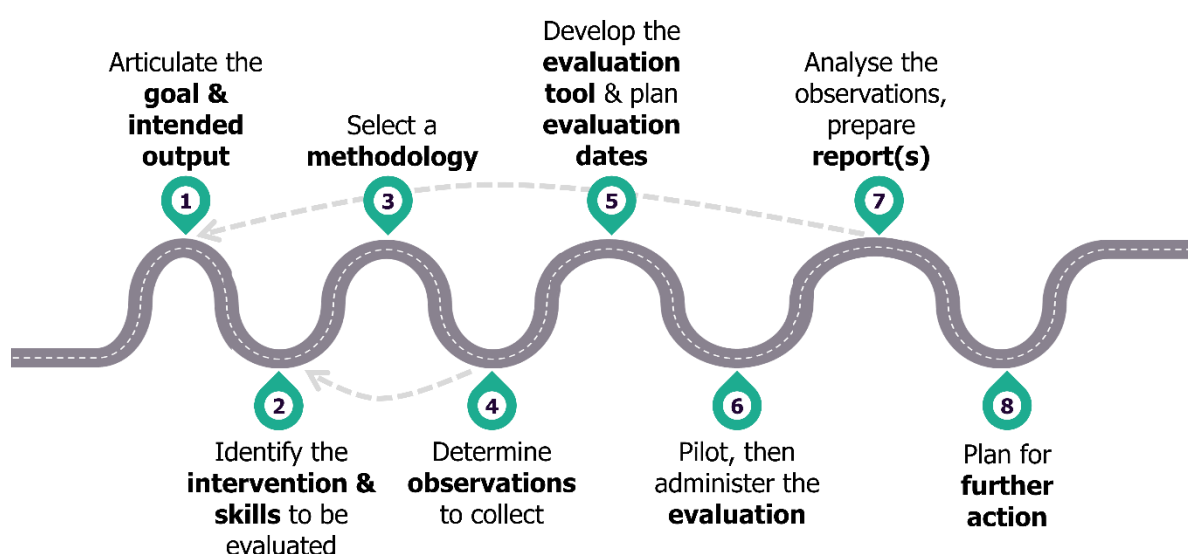


*Figure 5.4.1: A semi-sequential checklist for preparing an evaluation.
Own Work by de Lima*

Step 1. Start by clarifying why you are conducting an evaluation, including how the results will be documented to reach your intended audience. Depending on your motivations, relevant outputs might include an internal report, a conference paper, or your tenure committee. Having a concise record of your goals assists in maintaining a coherent approach.

It is important to distinguish between assessment of learning and evaluation of an intervention. In general, assessments are conducted to determine students' performance in a module, while the objective of evaluation is to improve the intervention. Evaluation focuses on understanding how and why an educational intervention contributed to student learning and other outcomes. Many methods used in assessment can also be used in evaluation, and one can support the other.

Step 2. Next, clearly specify the educational intervention being evaluated. Due to expectations that these skills are implicitly developed in higher education (Dokter, 2024; Isaac et al., 2023), and since they are often described too broadly (e.g., communication skills), it may be necessary to describe the transferable skills with adequate specificity to allow for meaningful evaluation. You could use the Activity Design Worksheet A by Isaac and de Lima (2024, pp. 195-197) to guide your process of clarifying the specific skills and granularity that will be your focus. When describing the intervention to be assessed, specify the time frame, participants, and other elements that are relevant to planning.

Step 3. There are multiple methodological options for evaluating interventions that develop transferable skills. The appropriateness of each depends on your evaluation goal, for example whether you aim to understand student experiences, document behavioural change, or compare alternative educational designs. Before deciding, we recommend considering a couple of options:

- *Participatory strategies*, such as engaging with students as partners, or collecting observations from project supervisors or future employers, can bring in rich perspectives.
- *Qualitative methods*, such as interviews, can help you explain how and why an intervention works.
- *Quantitative methods*, which are useful when you want to compare groups or track changes over time.

Selecting a method involves determining both the measure that will enable you to assess the impact of the intervention and the implementation approach. Large-scale questionnaires may seem most accessible but should be used with consideration after exploring alternative methodologies in the literature. Two final elements to consider in selecting your method are how you will reach your desired population for data collection (obtaining sufficient representativity, diversity, or quantity depending on your methodology) and what resources are needed for collecting, cleaning, and analysing data (distribution, transcription, etc.). A decision grid that lists possible approaches along with their associated benefits and constraints can help you to make well-informed decisions. Revisit and refine your response to step 1 to ensure your approach stays aligned with your goals.

Step 4. Decide what data you will collect, from which stakeholders, and on which aspects. For example, to compare students' perceptions of transferable skills development in client-based projects versus more traditional academic ones, it may be more effective to survey students with experience in several projects. Other

potential approaches include documenting educators' experiences with implementation, comparing costs, analysing transferable skill learning outcomes across the curriculum, observing how teaching assistants interact with students, or tracking participation across student profiles. If you conclude that assessing students' skills themselves is most appropriate, we recommend turning to Part 3 of this handbook.

Step 5. You are ready to start developing the evaluation instrument, i.e., the questions, task, or situation that will allow you to gather the data you need. Using a previously developed instrument, such as a validated questionnaire or set of interview questions, strengthens your study by providing conceptual coherency and a potential baseline. These are important benefits that are unfortunately underutilised in education (Buntins et al., 2021). In addition to developing an instrument to elicit relevant data, you must consider *when* to collect your data to best capture relevant information about transferable skills.

In parallel, plan logistics such as dates, physical or digital resources, and clear information to encourage your target audience to participate. Verify if your institution and/or intended publication venue require ethical approval and account for potential delays in obtaining approval. In all cases, be mindful of ethical considerations and only collect the necessary data to accomplish your evaluation goals and ensure participants have consented to participate (informed consent).

Some examples of data collection instruments are:

- *Self-assessment questionnaires* targeting the learning experience (e.g., based on the 3T PLAY framework for experiential interventions; Isaac & de Lima, 2024, p. 17 and Chapter 2.10) or targeting different skill categories (e.g., at the end of a project-based module; Tormey & Laperrouza, 2023) and other methods as discussed in Chapter 3.2 on self-assessment.
- *Classroom observations* either using video recordings or by asking a colleague to observe your teaching (Guimarães & Lima, 2021).
- *Interviews and focus groups* with your students.
- Analysing *student artifacts* such as reports, reflections, online discussion posts, learning journals, or portfolios.
- *Digital learning analytics* or trace data that measures online engagement and submission patterns in your online course environment.

Step 6. Conduct a pilot evaluation to identify potential problems. Piloting saves time by ironing out issues before data collection and can often be done while waiting for ethical approval. Test both technical and conceptual issues under conditions as close as possible to those planned for your implementation. Our personal experiences of off-campus students being unable to open hyperlinks, too much background noise, and video file formats being incompatible with data processing software illustrate the benefits of piloting every technical step. Conceptual piloting ensures a shared understanding of the instrument between yourself, your participants, and your colleagues. This can involve focus group discussions (to test your quantitative

instruments) or a test interview with a colleague, followed by transcription and analysis (including inter-rater reliability analysis with colleagues) using your intended tools. Build in flexibility by planning extra time, data collection dates, additional participants, etc. to ensure that last-minute technical issues or incomplete sessions do not derail your entire evaluation.

Step 7. When starting your analysis, ensure that your analysis is focused and grounded by reminding yourself of the original questions and intended outcomes. Applying a relevant conceptual framework throughout the process will help you interpret your findings with greater depth and provide you with a clearer perspective on the implications of your results. Consider re-engaging with your stakeholders, such as your research participants or your intended audience, during your analysis phase to enrich your interpretation. When writing your results, keep your initial objective and your target audience in mind. It may be most effective to prepare two documents, such as a journal article and an internal report, each tailored to the needs of that audience. Avoid bias, such as underreporting negative findings or overstating positive outcomes (Cohen et al., 2018; Miles et al., 2020). We refer you to Chapter 5.6 for further information on dissemination of your results.

Step 8. The final step is to consider what actions should be undertaken based on your findings. This can include ideas for improving this specific intervention, additional interventions, or conducting another evaluation. Clear recommendations increase the value of your evaluation and increase the likelihood of constructive implementation. When communicating your results, be strategic and align your findings with institutional goals, when possible (Soliman et al., 2019), while being mindful of reporting bias (Dawson & Dawson, 2018). This can strengthen your case, for instance when advocating for funding. When preparing communications for policy makers or academic audiences, take a scholarly lens by contextualising with literature, including critical perspectives and implications. Your reporting should allow your audiences to make decisions, so be explicit in your recommendations. For guidance on how to use your evaluation to maximum effect, see Section 5.

3.2 Integrative approaches for evaluating interventions

Over the years, many methods of evaluating teaching interventions have emerged, such as student ratings, peer or expert reviews, and video analysis, each offering a different perspective. What is important is not just measuring learning outcomes but also capturing the context, processes, and lived experiences that shape them.

Self-reporting by teaching staff is one way of doing this. Such reflective narratives often highlight why an intervention was tried, the strategies used, and how the module evolved based on student feedback. Compiled into teaching portfolios (Seldin, 1993), they provide rich insights and remain a valuable tool for both documenting practice and driving continuous improvement (Braskamp & Ory, 1994).

When we look at teaching interventions, it is not enough to merely ask 'does it work?' We also need to ask how and why it works, and under what conditions. For a while, the evidence-based movement (Hammersley, 2007; Hanley et al., 2016; Pring &

Thomas, 2004) leaned heavily on randomised controlled trials (RCTs), because they gave clear, generalisable results (Connolly et al., 2018; Torgerson & Torgerson, 2003). However, critics have pointed out that while RCTs are useful to establish replicable outcomes, this reductionist approach fails to reflect the complexity of real-world educational settings (Connolly et al., 2018; Outhwaite et al., 2020). By focussing on statistical generalisation, such methods can disconnect interventions from the contexts in which they are embedded (Elliott, 2001). Instead, we need to pay closer attention to how interventions are implemented and evaluate the process of implementation through a holistic approach.

Researchers also caution against a heavy reliance on self-report questionnaires, varied study designs (many lacking control groups), and an overall absence of evidence demonstrating real-world transfer (Tyne et al., 2024). These issues reflect wider challenges in evaluation, such as insufficient mapping of interventions to learning objectives, over-reliance on surveys, lack of baseline data, unbalanced use of quantitative versus qualitative data, poorly defined evaluation criteria, and missing justifications grounded in evidence or theory. A more integrated approach is required to solve such issues.

Another tricky challenge is figuring out how to evaluate multiple goals of an intervention at once. Take the example of project-based learning: you might want to know if it boosted student performance, improved client satisfaction, and motivated students and educators — all at the same time. To handle this complexity, we need structured ways to capture the bigger picture. Venezky (2001) suggested two useful tools. One is the History of the Future exercise, where you imagine the intervention fully succeeding and draft a future press release about what was achieved, how it worked, and why it mattered. The other is Programme Logic Mapping, which visually connects inputs (like the intervention) to outputs (such as better engagement) and intermediate outcomes (like educator behaviour changes). Together, they help clarify goals, test assumptions, and create a more coherent evaluation.

4 Implications for evaluating interventions that develop transferable competencies and skills

It is important to consider the quality of the evaluation itself. Evaluations demand resources from multiple stakeholders (e.g., students, instructors, institutions) and can have significant consequences for the future of the intervention and institutional goals and credibility. Poorly designed evaluations risk pedagogical misalignment, misallocated resources, damage to the institution's reputation, and erosion of trust between the various stakeholders including accreditation bodies. However, well-designed and implemented evaluations can improve learning locally and support larger-scale adoption.

This section is designed to help you as an educator to evaluate your interventions, or to assess the quality of an evaluation done by another educator. It briefly introduces criteria that can be used for this purpose, provides practical ideas and a checklist (Fig. 5.4.2), and uses two mini case studies of educators that operationalise the evaluation

quality criteria in interventions that develop transferable competencies and skills to help you contextualise the criteria (Tables 5.4.2 and 5.4.3). There are several resources that can provide you with further support and details for the quality of evaluation (e.g., American Educational Research Association [AERA] et al., 2014; Cruz et al., 2019; Gullickson, 2003; Messick, 1995; Organisation for Economic Co-operation and Development, 2021; Yarbrough et al., 2010).

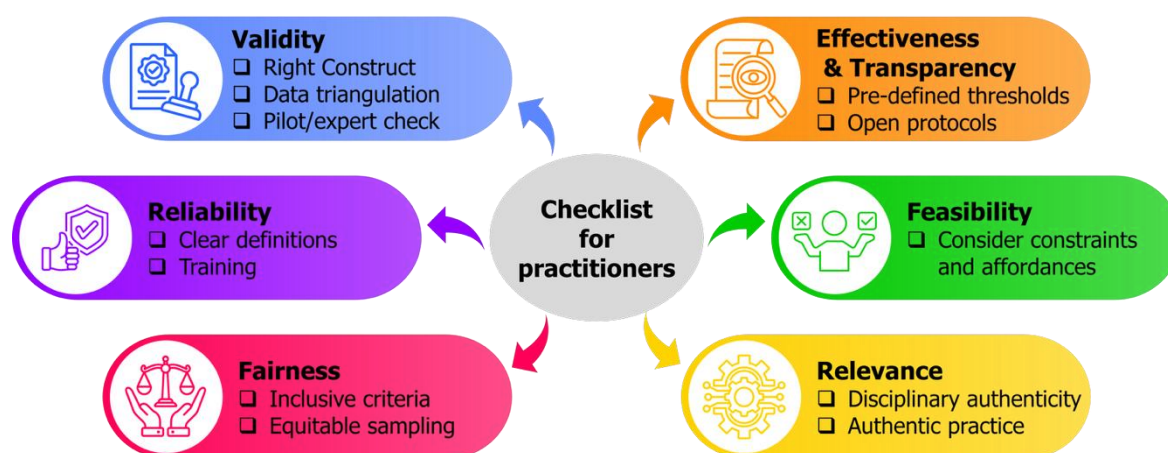


Figure 5.4.2: Checklist for practitioners who seek to evaluate the quality of evaluations. Own Work by de Lima

Validity considers if the data genuinely say what you think it does. While validity can include several aspects, we focus on this key question: do you trust the claims or inferences made from the evaluation results? To assess validity, ask:

- Are you measuring what you intended to measure? Staying aligned with your goals will prevent getting sidetracked by irrelevant details.
- Are you using multiple sources of data? Considering multiple stakeholders, perspectives, and types of data will allow for triangulation and strengthen the credibility of your findings.
- Did you pilot your instruments, or have an expert review them? This will help early detection of potential issues with validity, gaps in the data, or unintentional outcomes.

Reliability considers the consistency of the data obtained in the evaluation process and focuses on how data is collected and analysed. This means that if other people conducted the evaluation, they would reach similar results. To assess reliability, ask:

- Do you have clear operational definitions or well-defined rubrics? Clear criteria reduce ambiguity and ensure that everyone measures the same thing in the same way.
- Are data collectors and analysts trained and following the same procedures? This ensures consistency and reduces variation caused by individual judgements or different approaches.

A *fair evaluation* explicitly accounts for diversity in individuals and contexts and actively mitigates potential biases. To assess fairness, ask:

- Do the benchmarks account for diverse participants and ways of participating? This avoids systematically marginalising or privileging certain groups.
- Are your sampling and analysis equitable? Collecting data across different times and groups while minimising unnecessary burden on the students/observers/analysers supports fairness.

Feasibility involves being realistic about the resources available in your context, especially when replicating an evaluation done in a different context. While integrating evaluation into the intervention design can assist, assess feasibility by asking:

- Have you considered each part of the evaluation alongside your affordances and constraints? Aligning design, data collection, and analysis with available expertise, time, and tools ensures feasibility.
- If the original plan is not feasible, what is the most you can do with available resources? You may need to adjust your evaluation goals.

The evaluation should be *relevant* for your teaching or your institutional goals and preferably align with broader disciplinary and global needs. In engineering education, relevance means the questions, methods, and claims are authentic to the discipline and linked with professional standards, ideally informing accreditations, curriculum design, or graduate career trajectories. To assess relevance, ask:

- Is the goal aligned with industry needs or accreditation standards?
- Does the evaluation mirror authentic disciplinary practices?

Effectiveness determines if an evaluation meets its intended goals. Therefore, setting clear goals and targets at the outset is essential. However, results should be interpreted in context, considering the possible factors that contribute to differential results for sub-populations, and the relative importance they hold for different stakeholders. To assess effectiveness, ask:

- Did you set clear goals and targets, and did the evaluation provide credible evidence to demonstrate achievement? Strong evidence should withstand peer scrutiny.
- Are the results different for any sub-populations, and can you determine which factors most influenced the outcomes? Understanding these differences will support meaningful interpretation.

Transparency means giving visibility to typically invisible aspects, so that stakeholders can understand, trust, and if necessary, critique the evaluation. It is important to get a nuanced understanding of an evaluation. This is well established in fields like medicine (Cotterill et al., 2018) and increasingly called for in higher education (Shavelson, 2010). To assess transparency, ask:

- Is the process of gathering and analysing data well documented? Clear records allow peers to understand exactly what was done, and why.

- Have you been explicit about the limitations of your method, data, analysis, or claims? Acknowledging constraints adds credibility, not weakness.
- Does the reader understand your role and motivations? Knowing your position helps the reader interpret your perspectives.

To help you contextualise and adopt the criteria we have used two mini-cases of educators that operationalise evaluation quality criteria in interventions that develop transferable competencies and skills (Table 5.4.2).

Table 5.4.2: Mini case studies illustrating strategies that improve validity, reliability, fairness, feasibility, relevance, effectiveness, and transparency in the evaluation of teaching transferable competencies and skills.

<i>Context</i>	<i>Case 1: an educator implemented a short active learning activity in their module designed to improve communication within teams.</i>	<i>Case 2: an educator was asked to review their department's internships for an upcoming accreditation.</i>
<i>Goal of evaluation</i>	They want to <i>measure students' behavioural engagement</i> during the activity.	They need to <i>assess the impact of internships on students' transferable skill proficiency</i> .
<i>Strategies that improved</i>  Validity	The educator collected data about actual behavioural engagement using a validated protocol.	The educator collected the students' reports and implemented a pre- and post-internship questionnaire data assessing students' skill proficiency, from multiple sources (students, supervisors, and a control group of non-participants).
<i>Strategies that improved</i>  Reliability	The educator used a rubric with clear definitions, e.g., only count when a student verbally clarifies a concept to a peer.	The educator trained raters by having them grade five anonymised reports to compare scores and resolve discrepancies.
<i>Strategies that improved</i>  Fairness	The educator asked two colleagues to be observers; they focussed on multiple behaviours, not just verbal interactions, to avoid disadvantaging students with fewer verbal skills.	The educator gathered multiple types of data from multiple stakeholders.

<i>Context</i>	<i>Case 1: an educator implemented a short active-learning activity in their module designed to improve communication within teams.</i>	<i>Case 2: an educator was asked to review their department's internships for an upcoming accreditation.</i>
<i>Goal of evaluation</i>	They want to measure students' behavioural engagement during the activity.	They need to assess the impact of work-based internships on students' transferable skill proficiency.
<i>Strategies that improved</i>  Feasibility	The educator determined that their team does not have expertise to develop a new instrument but has expertise in quantitative data analysis skills. So, they could use a previously validated protocol with a strong quantitative component.	The educator determined that the report templates and questionnaires already existed, and they could expect a high response rate. However, they would need to budget for external qualitative data analysis.
<i>Strategies that improved</i>  Relevance	This evaluation is relevant as communication in teams is both an authentic disciplinary practice and part of engineering programme accreditation criteria.	This evaluation is relevant as transferable skills are emphasised in accreditation criteria, and the findings could have implications for all institutions with internships.
<i>Strategies that improved</i>  Effectiveness & Transparency	The educator's report showed a 25% increase in oral interactions, exceeding the 20% goal, with the caveat that online interactions were not captured. It included anonymised data and noted limitations (observer presence influencing student behaviour).	The educator's report demonstrated effectiveness, as supervisors' perceptions of student skill proficiency increased after the internship, and also included the questionnaire and limitations (potential conflict of interest as their departmental accreditation depends on demonstrating the effectiveness of the intervention).

5 Recommendations for teaching practice

Evaluating interventions that teach transferable competencies and skills should not rely exclusively on student opinion questionnaires or grades. Using multiple sources for data collection will help you make sense of how well your interventions meet your goals and why (or why not). Of course, the approaches discussed in this chapter should always be adapted to local contexts.

The true value of an evaluation lies in using the findings to improve how we teach transferable skills in engineering students. Bringing in different perspectives and triangulating your data can provide important and useful insights (Patton, 2015). When sharing the findings of your evaluation, consider both the intended audiences and the best way to support constructive engagement with the results. Different stakeholders value different types of information, so clarify how the findings should inform their decisions and what actions from them can lead to meaningful change. Colleagues, administrators, student representatives, or external stakeholders may need to examine and digest your findings before they will be ready to act on them. Rushing this phase can increase resistance to change, especially when findings oppose common practices or institutional norms. We refer to Chapter 5.6 for further information on dissemination of your results.

Ideally, evaluating interventions should not be treated as a once-off event but as part of the continuous improvement of our daily teaching practice. We encourage you to embed it into routine activities by drawing on evidence from student project work, reflective assignments, feedback moments, and classroom interactions. Systematic collection and review of this evidence aligned with existing teaching tasks can make the evaluation of interventions efficient and sustainable. For more information about the systematic use of assessment data to evaluate educational outcomes and improve programmes, see Chapter 5.3.

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5.5

Conducting Comparative Reviews of Transferable Competencies and Skills Instruction across Institutions

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Analysing how different programmes and institutions instruct transferable competencies and skills can provide educators, researchers, educational developers, and administrators with valuable models to inform their practice or programme. Yet despite their value, relatively few of these reviews are found in the literature. This chapter examines different approaches to conduct a comparative review, including literature and document reviews, surveys, interviews, and engaging with scholarly communities, and shares advantages and disadvantages of each. We consider the challenges of conducting a comparative review through a case study of our own project to understand communication instruction in engineering education in Canada. Throughout this chapter, we emphasize the relationship between purpose, method, design, and scope, and argue that a review is most successful when the researcher is adaptable and persistent. We recommend that as a community we focus efforts on facilitating scholarly conversations about transferable competencies and skills instruction, consistently mapping, archiving, and disseminating our work, as less frequent engagement complicates the review process.

1 Introduction

Analysing how transferable competencies and skills are taught and assessed in different programmes and institutions can provide educators, researchers, educational developers, and administrators with valuable models to inform their own practice or programmes. Transferable competencies and skills, those that complement engineering practice but exist across and between engineering specialisations, are broadly applicable across learning and workplace contexts. They include skills such as critical thinking, project management, leadership, communication, and teamwork. Given their practical orientation, transferable competencies and skills are typically taught and practiced in hands-on learning environments, and pedagogical practices are often shared in papers and conference presentations focused on specific classrooms and interventions. Comparative reviews, which compare practices across modules or institutions, are less common but valuable in helping programme planners to understand trends and activities in transferable competency and skill instruction.

This chapter examines how scholars conduct comparative reviews to analyse how transferable competencies and skills are taught across modules, programmes, and institutions. For manageability, we scope this chapter to a single transferable skill: communication. However, this discussion is relevant to other transferable competencies and skills covered in this text. We begin by providing a general rationale for conducting comparative reviews and discussing the factors that impede their ease. Then we introduce comparative reviews of communication skills found in the literature and discuss the approaches taken and the challenges and advantages of each. Following this, we share a case study of our own comparative review of communication skills in engineering education in Canada to demonstrate the practical application of evaluating instruction across institutions. We conclude the chapter by considering the larger implications of the work done and methods chosen to evaluate transferable competencies and skills instruction across programmes in engineering education and provide recommendations and implications for practice.

2 Context

A comparative review of transferable competencies and skills instruction across modules, programmes and institutions may be conducted for a variety of reasons. Educators teaching or developing a new module or module sequence can draw on similar modules for ideas. Educators advocating for more focus or support in transferable skill instruction can use successful models to illustrate value and effectiveness, and advocate for change. Administrators or curriculum developers integrating more support for transferable competencies and skills will benefit from reviewing other administrative models to consider where skill integration can best be situated and supported. Meta-studies in this area can provide the most compelling evidence to shift institutional and staff attitudes about the importance of transferable competencies and skills. Yet despite the usefulness of comparative reviews, relatively few exist. This means there are few shortcuts to attaining a broad understanding of how specific transferable competencies and skills are taught; we are unlikely to find a

comparative review in the literature that fits our specific skill, needs, and context. Instead, we need to define our own goals, select appropriate methods to accomplish them, and tap into the available resources to help us conduct our review.

Several factors impede the ease with which we can conduct comparative reviews. First, transferable competencies and skills instruction in engineering is situated and supported differently across institutions. We can be fairly confident about where to find a thermodynamics class (chemical engineering) or a building science class (civil engineering), but we cannot have that same surety about where to locate — or even if we *can* locate — the instruction of leadership, communication, or other transferable competencies and skills in an engineering curriculum. Transferable competencies and skills may be integrated across the curriculum (often heavily and inequitably concentrated in first-year cornerstone or senior year capstone design modules), instructed via standalone modules within the faculty, developed in co-instructed or partnered modules taught by engineering staff and skill specialists, or delivered via 'service modules', which are housed within a faculty outside of engineering but designed to meet engineering curriculum requirements. Administratively, instruction may be the responsibility of individual engineering departments within a faculty, organized centrally in a professional skills unit — for example a communication or leadership institute — or provided via service modules offered by other faculties. The variety of instructional and administrative models for transferable competency and skill development makes any review complicated but is also why a comparative review is valuable: there are many possibilities to consider.

Second, information on instructional approaches to transferable competencies and skills is also dispersed across diverse scholarly channels, which is unsurprising given the lack of a consistent instructional home for transferable competencies and skills. Transferable competencies and skills specialists may share their work within communities focused on their niche area. For example, an engineering communication educator might present at the IEEE Professional Communication Society or publish in IEEE Transactions. They may share their work with the broader engineering education community at the European Society of Engineering Education (SEFI) or a regional engineering education conference, or with a writing and rhetoric community. The variety of scholarly channels complicates locating and reviewing instructional approaches. Another important consideration in reviewing different approaches is that the practical nature of skills instruction produces many conference presentations, but fewer journal papers. Conference proceedings are not always indexed in public databases, and therefore not always easy to locate. Furthermore, some transferable skill activities may not be shared in scholarly channels at all, especially when scholarly contributions are not an expectation of the educator's position or not aligned with their primary research interests. For example, modules may be supported by external disciplines or by administrative staff without research agendas or assigned to teaching staff with research agendas focused on other areas. As a result, there may be significant gaps in our understanding of the pedagogies of transferable competencies and skills in the engineering education landscape.

Third, discussions about transferable competencies and skills often lack a consistent language. For example, in their introduction to the *Journal of Academic Writing*, Gustafsson and Jacobs (2013) emphasize the range of specialisations and corresponding nomenclature for communication skills in higher education. For example, English or Language Studies covers an exhaustive list of subspecialisations: English as a Second Language (ESL), English as a Foreign Language (EFL), English for Academic Purposes (EAP), English for Specific Purposes (ESP), Writing Across the Curriculum or Within the Discipline (WAC/WID), and many more. They note regional influences in subcategories of genre theory, specifically Rhetorical Genre Studies (RGS) in North America, Systemic Functional Linguistics (SFL) in Australia and English Language for Specific Purposes (ESP) in Europe. While the distinction between these specialisations may be unclear to someone outside that field, each encapsulates distinct scholarly or instructional orientations. Paretti and McNair (2008) also demonstrate the contextual specificity of language. For example, in their introduction to the *IEEE Professional Transactions Special Issue on Communication in Engineering Curricula*, the authors predict a shift away from WAC/WID to Communication Across the Discipline (CXD) and Communication in the Discipline (CID), as instruction expands to cover multimodal communication. The number of niche descriptors and acronyms, coupled with the potential of these to shift with region and time, significantly complicates how we find and make sense of transferable skill activities and scholarship in this field. Overall, for all these reasons, locating up-to-date and relevant information on how transferable competencies and skills are taught and learned in engineering curricula is challenging.

3 Approaches to analysing transferable competencies and skills: communication instruction across modules and institutions

Communication instruction is a helpful example through which to examine comparative reviews of transferable competencies and skills instruction. This area has active local and international communities of scholars in engineering education, and as communication educators, the authors have studied and published on this topic.

Paretti (2008), who has published on communication for over two decades, cites the wealth of articles on the subject as evidence for its importance. Dyke Ford & Riley (2003) concur. Notably, within a North American context, much of this scholarship has been motivated by accreditation requirements. It has been over two decades since ABET — the programme responsible for accrediting engineering programmes in the United States — added communication to its accreditation requirements with the release of Engineering Criteria 2000 (Marshall et al., 2019). The Canadian Engineering Accreditation Board's (CEAB) shift to outcomes-based criteria in 2008 (Klassen & Sá, 2020), included communication in its newly structured criteria. Within the UK, the Engineering Council's UK-SPEC (United Kingdom's Standards for Professional Engineering Competencies) released its first outcomes-based guidance document for accreditation in 2003 (Engineering Council, 2025), and this too includes communication. In Europe, the significant number of regional accreditation bodies

affiliated with the European Network for Accreditation of Engineering Education (ENAAEE) results in a long and varied list of guidance documents shaping engineering competency priorities (ENAAEE, 2022). But here too, the importance of communication as a signifier of professional readiness motivates attention to this subject. Indeed, feedback from industry and alumni on the importance of communication skills in the workplace also motivates significant activity in this area (Reave, 2004).

As part of this section, we refer to several methodologies and methods that our reader may or may not be familiar with, particularly in Table 5.5.1. For those interested in exploring these more, we refer to these research methods textbooks: For general research methods in education, Cohen et al., (2018)., Fink (2019) on conducting literature reviews, Fowler (2014) on Survey research and Creswell & Poth (2018) on qualitative research methods, where interested educators can find these methodologies and methods defined and explained. Methods used to conduct comparative reviews published in the literature include:

- *Literature-based methods*, including narrative, confirmatory, systematic, and meta-analytic reviews of journals and conference proceedings, cluster analysis and historical reviews (e.g., Buswell et al., 2019; Hutchison et al., 2021; Leydens & Schneider, 2009; Mann et al., 2007; Paretti, 2008; Paretti et al., 2007, 2023; Patterson, 2017; Patton, 2008);
- *Surveys and questionnaires*, used to compare educator beliefs, instructional practices, barriers, or institutional norms (e.g., Buswell et al., 2019; McKenzie et al., 2004);
- *Interviews*, conducted in person, online, by phone, or email, with faculty, administrators, or programme directors (e.g., Leydens & Schneider, 2009; Marshall et al., 2019; Matusovich et al., 2012; McKenzie et al., 2004; Reave, 2004);
- *Website reviews*, including internet searches of universities, programmes, researchers/educators, research groups, relevant practice (e.g., Leydens & Schneider, 2009; Marshall et al., 2019);
- *Document reviews*, such as programme descriptions (e.g., Leydens & Schneider, 2009);
- *Engagement, observation, and disciplinary conversations within scholarly communities*, in colloquia, and formal and informal capacities (e.g., Buswell et al., 2019; Gustafsson & Jacobs, 2013; Leydens & Schneider, 2009; Marshall et al., 2019).

For a few of these methods, namely literature-based methods, surveys and interviews, researchers used a 'snowballing' approach to accrue additional participants and information via personal and professional networks, and colleague referrals (e.g., Buswell et al., 2019). Overall, many researchers employed a combination of methods.

There are also common designs for the comparative reviews, which include:

- Qualitative case studies (Bazerman & Prior, 2004; Kirsch & Sullivan, 1992; Mosenthal et al., 1983; Paretti, 2008; Winsor, 1996);
- Multi-case studies comparing institutions or programmes (e.g., Dyke Ford & Riley, 2003; Leydens & Schneider, 2009);
- Landscape studies mapping practices across institutions in national and international contexts (e.g., Hutchison et al., 2021; Marshall et al., 2019);
- Colloquia or community-based studies emphasizing disciplinary conversations and shared norms (e.g., Gustafsson & Jacobs, 2013; Leydens & Schneider, 2009);
- Mixed methods studies (e.g., Hutchison et al., 2021; Marshall et al., 2019).
- Longitudinal studies (e.g., Winsor, 1996);
- Theory-driven comparative studies guided by paradigmatic theoretical perspectives, such as Situated Learning and Activity Theory (Paretti, 2008), Genre Theory (Miller, 1984), and Motivation Theory (Matusovich et al., 2012).

Though researchers began with a set study design, many had to adapt their data collection method when initial approaches did not capture the targeted data or change how a participant could respond to their method. For example, Reave (2004) used 'surveys' that were in fact interviews and conducted these with phone calls and emails; McKenzie et al. (2004) turned interview protocols into surveys so participants could do them online. We did not notice researchers using focus groups, examining engineering accreditation documents, or conducting site visits, despite the wealth of information available via this approach (Mattucci, 2019). Nor did we notice much variation in types of research design. For example, there were no examples of narrative inquiry, participatory action research, phenomenology, or ethnographies. Researchers carefully bounded their reviews with different units of analysis, scales, populations, and foci, diverging across:

- *Unit of analysis:* modules, programmes, institutions, or disciplinary communities.
- *Scale:* single institution, multi-institutional, national, or international.
- *Populations and foci,* including:
 - communication or writing modules;
 - capstone modules (McKenzie et al., 2004);
 - writing-across-the-curriculum initiatives (Buswell et al., 2019);
 - writing and communication programme administration (Patterson, 2017);
 - 'top-ranked' institutions (Besterfield-Sacre et al., 2014; Reave, 2004);
 - English-speaking institutions (Reave, 2004);
 - students participating in internships or work experience (Winsor, 1996);
 - communication skills paired with teamwork (Matusovich et al., 2012).

Overall, studies had a pragmatic aim: to acquire information on communication skills within a set scope, often to inform module or programme design. For a comparison of methods, data captured and characterization of each method's usefulness, see Table 5.5.1.

Table 5.5.1: Methods for conducting comparative reviews

<i>Method</i>	<i>Variants</i>	<i>Data captured</i>	<i>Usefulness</i>	<i>Examples in literature</i>
<i>Literature reviews (secondary data)</i>	Narrative, systematic, confirmatory, cluster analysis, meta-analyses	Published patterns across sites/time; conceptual framing; typologies	Provides a field map, or state of the art comparison for identifying trends or gaps	Buswell et al. (2019); Hutchison et al.; (2021), Mann et al., (2007); Paretti, (2008); Paretti et al., (2007, 2023); Patterson, (2017); Patton, (2008)
<i>Surveys (primary data)</i>	Often paired with follow-up interviews; sometimes converted from interview protocols	comparable responses across institutions and programmes; broad coverage	Provides breadth or a standardized comparison across many respondents	Buswell et al. (2019); McKenzie et al. (2004)
<i>Interviews (primary data)</i>	In-person, online, phone, email	Explanations, rationales; decision logics; contextual detail	Provides depth, nuance, and interpretive comparison across cases	Leydens & Schneider (2009); Marshall et al. (2019); Matusovich et al. (2012); McKenzie et al. (2004); Reave (2004)
<i>Website reviews (secondary data)</i>	Structured searches; targeted site sampling; triangulated with interviews or documents	Curricula outcomes; policies; module descriptions; public-facing representations	Enables a quick comparison of multiple programmes	Leydens & Schneider (2009); Marshall et al. (2019)

<i>Method</i>	<i>Variants</i>	<i>Data captured</i>	<i>Usefulness</i>	<i>Examples in literature</i>
<i>Document reviews (secondary/internal artifacts)</i>	Module, programme, institutional, regulatory	Policies; curricular documents; programme descriptions; internal reports; official programme structure	Provides a comparison of administrative structures or formal requirements	Leydens & Schneider (2009)
<i>Engagement/observation/scholarly community conversation (primary/participatory data)</i>	Conference attendance; community engagement; colloquia; informal conversation; field notes	Field norms; discourse; emergent practices; community sense-making	Captures emerging and/or unpublished community-based practices and disciplinary trends	Buswell et al. (2019); Gustafsson & Jacobs (2013); Leydens & Schneider (2009); Marshall et al. (2019)

In the following subsections, we examine five of the more common methods: literature reviews, document reviews, surveys, interviews, and engaging in scholarly communities. We use representative studies from the literature and experiences within our community to evaluate their use, affordances and limitations.

3.1 Literature reviews

A literature review is likely the first strategy that comes to mind when analysing across modules, programmes and institutions. Literature reviews are useful to situate practices within context, acknowledging how these have evolved from a theory or been inspired by other practitioners. Within larger analyses, literature reviews can provide a bird's eye view of what has been published on the teaching and learning of transferable competencies and skills, and how attitudes and practices differ between regions or have evolved over time.

Although we might gravitate towards a literature review when starting a comparative review of transferable competencies and skills, it is important to acknowledge the limitations of this approach. Discussions about transferable competencies and skills take place in a variety of academic spaces. Articles about best practices for communication instruction in engineering, for example, are found in a variety of journals. Given the practical nature of skills instruction, however, we may be more

likely to find this scholarship within conference proceedings than within journals, and conference proceedings may be non-indexed or indexed in idiosyncratic ways.

Because literature on communication instruction is so widely dispersed, a comprehensive review is very difficult to achieve; it is important to acknowledge the limitations of a literature review and scope accordingly. If we are interested in understanding how communication instruction is integrated within a particular engineering context, we should look at that field's engineering education society proceedings. If we wish to understand how chemical engineering professors integrate communication into their modules, we might search chemical engineering education journals or turn to conference proceedings from a chemical engineering society. The choice of source will impact the type of information available. It is also important to acknowledge that a literature review will only capture information from practitioners actively working to disseminate their work. Non-research stream educators, who in some regions, like Canada, comprise a significant portion of communication educators, may be less motivated to publish or present their work due to a lack of financial support or performance incentives.

Paretti (2008) and Paretti et al. (2007, 2023) use literature reviews to understand how different pedagogical strategies are deployed to teach communication across engineering programmes. Their 2023 review illustrates the relationship between source and scope. By looking exclusively at papers published in the American Society for Engineering Education's (ASEE) annual conference proceedings, the authors limit the approaches discussed to those used by educators who are actively engaged in this engineering education community, and privilege American perspectives.

Hutchison et al. (2021) use a literature review to explore instructional approaches to communication and identify their theoretical grounding. Their review traces citation patterns, using Miles and Huberman's (1994) descriptive framework to identify communication theories underpinning instruction at Cornell, and tracing the use of these citations by other scholars in the field. This method constrains the number of programmes represented to a manageable number and purposefully limits the diversity of programmes: by focusing on programmes shaped by similar theories, the paper showcases like-minded scholars and educators.

Some researchers scope their literature review by focusing on a niche topic within the instruction of a given transferable competency and skill. Patterson (2017), for example, analyses the organizational structures within which communication instruction occurs, reviewing writing by and about programme administration to identify historical trends. Mann et al. (2007) review integrative communication in a biosystems design module sequence. Matusovich et al. (2012) review programmes that integrate communication and teamwork skills.

Overall, literature reviews provide you with a useful entry point by introducing key scholars, theories, and pedagogical approaches. They are limited, however, by two

factors: (1) they cannot capture all contributors and perspectives without becoming unwieldy; and (2) they amplify scholars who publish on their work with transferable competencies and skills, overlooking practitioners who do not disseminate their work in this way, or at all. As such, they are most manageable when thoughtfully scoped for a specific purpose using appropriate sources, and most meaningful when the limits of this scope are clearly understood and articulated.

3.2 Document reviews

As noted above, a shortcoming of literature reviews is their amplification of educators who publish scholarship about their practice. Using firsthand documentation to review different programmes offers a more comprehensive approach to learn about activities across many institutions and potentially captures information on instruction that is not shared in the literature.

Website reviews provide access to locate basic documentation, including module requirements and descriptions, and sometimes module educators and syllabi. A keyword search for different programmes may be a practical place to start for this type of programme analysis. For example, Liu and Tran (2022) utilized a website review to locate and analyse higher education programmes self-described as 'transdisciplinary', providing a snapshot of activities falling under this umbrella term.

While a website review promises basic access to some programme information, website conventions, as well as the range of approaches by which transferable competencies and skills are taught, complicate this method. Because transferable competencies and skills are often integrated into core engineering modules, it may be difficult to separate out the transferable skill under investigation. Given that many websites are focused on outreach — for alumni and current and prospective students — content may be promotional in nature, showcasing particular modules, activities, or centres over others, and as a result providing an incomplete picture of curricula and activities. Moreover, because transferable competencies and skills are often perceived as secondary to traditional engineering skills, such as design and problem solving, some websites are designed to cater to this dominant view of engineering, making it difficult to locate basic information on transferable competencies and skills. The process of collecting information from websites can also be inexact, with the potential, if information is found, to analyse out-of-date or archived materials.

There are other types of document review. Soliciting documents directly from module educators or administrators can provide more accurate and up-to-date information. For example, we can ask educators directly for their module syllabi or module descriptions, eliminating the need to navigate a website. While this approach may be more reliable and less time-consuming, it is most successful when we can call on an existing personal or professional network. It is also important to be aware of concerns around intellectual property when asking for module documents: establishing trust and transparency is important, and as a result this type of solicitation might be best combined with another method of information gathering, for example interviews. Accreditation documents, such as curriculum maps, can also provide a wealth of

information about how transferable competencies and skills are developed across multiple years within a programme.

Overall, a document review can provide significant information on how modules or programmes are run. While accessing documents through a website eliminates the need to engage with educators and administrators directly, it provides a filtered picture of activities, potentially obscuring important information. Soliciting documents directly from educators can provide a more complete picture and is most successful when the researcher builds trust with participants.

3.3 Surveys

Surveys are a useful method for gathering information on transferable competencies and skills directly from educators, administrators or students. Practically, the most significant time-investment when using a survey instrument is its design and interpretation, with less time spent on scheduling and connecting with individuals, as would be the case with face-to-face data gathering. These advantages make surveys a convenient tool, especially when the goal of the project is gathering broad perspectives. Nevertheless, surveys can be challenging, particularly in collecting enough responses. Most surveys require the use of an existing network of peers to help with recruitment.

Buswell et al.'s (2019) study of integrated communication in engineering illustrates the need to engage networks in survey distribution, and the flexibility that may be required to achieve meaningful response rates. The researchers sought to recruit engineering educators in order to investigate the degree to which writing practices are incorporated and assessed across the curriculum. They began by distributing their survey to engineering staff within their home institution; they next reached out to their colleagues at other institutions to help distribute the survey widely to academic staff; lastly, they distributed their survey to the American Big 10+ engineering deans' mailing listⁱ to further increase their sample. Their approach resulted in 190 survey respondents, calculated as a 10.7% response rate based on the total number of engineering staff at each of the Big 10+ institutions. The team acknowledges the challenge of measuring this response given the inexact nature of the approach to distribution. If publication is a research aim, the need to track and estimate a response rate is important; but if the primary purpose of the survey is to gather data to inform practice, it makes sense to privilege the widest distribution over enabling response-rate tracking.

Another factor to consider when using a survey approach is the level of detail and time commitment required by respondents. A survey that incorporates more open-ended answers and/or reflection will yield fundamentally different qualitative data than a multiple-choice survey. The former allows participants to describe or explain their specific instructional practices, while the latter can provide a higher-level snapshot of generalized practices. It is important to weigh the estimated time commitment of a

survey against the type of data desired and response-rate results. It is also important to respect and reward your colleagues' time.

An advantage of surveying is the customizability and potential focus of the instrument, the ability to distribute widely (e.g., locally, nationally, and globally), and the relative ease with which responses can be gathered. A disadvantage is the possibility of low survey responses, which may arise from a lack of incentive to participate given the arms' length nature of surveys and an academic culture of overcommitment and time constraints.

3.4 Interviews

Interviews are an effective way to promote discussion between participants and researchers and may be particularly valuable for those interested in probing for details on how transferable competencies and skills are taught and learned in unique contexts. Using an open-ended interview, we can respond to new information, pursue unexpected ideas and observations, and engage in shared disciplinary understanding with participants. Reave (2004), in arguably the most extensive first-hand study of engineering communication instruction to date, interviewed programme administrators to develop a comprehensive analysis of approaches to instruction in 73 top Canadian and US universities. In a smaller-scale study, Marshall et al. (2019) identified and interviewed 15 communication educators in chemical engineering to gather best practices for a nascent communication module within their own institution.

Like surveying, this method works best with access to an existing network of educators who are willing to share their expertise. As in Marshall et al.'s (2019) case, connecting with colleagues through mutual contacts can reduce barriers to participation. The process of recruiting participants and conducting the interviews can also help to form a new network. For example, Marshall et al.'s interviews led to a panel presentation at a national engineering education conference and also helped form connections with educators they could consult with while developing the module.

Although interviews provide an excellent vehicle for learning deeply about educators' experience, this approach is time-consuming and requires significant commitment from both the researcher and participant. Therefore, this approach is most appropriate to engage with a smaller population than, for example, surveys. Because this method can yield a significant amount of open-ended data requiring intensive analysis, it is important to budget sufficient time for this phase.

3.5 Engaging via scholarly communities

Both surveys and interviews rely on familiarity with programmes where the transferable skill is being taught, as well as educators working within this space; they target individual experiences and provide individual responses. Engagement in scholarly communities can stimulate action or facilitate group information sharing, thus garnering broader perspectives. Special Interest Groups (SIGs), which are often

smaller conference communities oriented around a particular theme, can be particularly useful for this type of scholarly engagement. Colloquia, designed to invite experts on a topic to share their insights and ideas through more formal presentations, provide another valuable opportunity for information sharing.

Though not required, information gathered in scholarly dialogue can also be published. For example, Leydens and Schneider (2009) invited members of the Conference on College Composition and Communication's Writing Across the Engineering Curriculum SIG to report on their respective programmes, information that then shaped follow-up interviews with these participants and led to a review article in the *Journal of Engineering Education*. Gustafsson and Jacobs (2013) used two colloquia to bring together scholars in South Africa and Sweden to share their perspectives on integrating communication before sharing these in a special issue of the *Journal of Academic Writing*. It is worth noting that the international orientation of these latter colloquia is particularly unique and distinct from the regional focuses that often occur within scholarly communities. The challenge of overcoming geographic and cultural barriers to bring together a variety of perspectives is a strength of Gustafsson and Jacobs' project, but more typically a limitation of gathering information from a single scholarly community.

4 Implications for practice

From our discussion of approaches above, it is clear that there is no 'one size fits all' approach to module, programme, or institutional reviews. How an analysis is conducted will depend on the purpose, context, and available resources of the researcher. Because comparative reviews are often conducted by educators to inform their own practice, these are often more fluid than a typical research project: the researcher may shift between methods without prior planning to respond to new information and new resources. The following case study from our own research provides an illustration of the challenges and opportunities of comparative institutional programme analyses, and emphasizes the adaptability needed for this type of project.

4.1 Case study: landscape analysis of engineering communication instruction in Canada

In the fall of 2024, we undertook a mixed-methods programme analysis of engineering communication instruction in Canada to respond to a gap in the literature since Reave's 2004 review of communication in Canadian and US universities. Her review was conducted by identifying the 23 English-speaking engineering universities listed in the 1998 Gourman rankingsⁱⁱ and then contacting and interviewing their administrators to learn more about the programmes. We were drawn to the systematic and inclusive nature of Reave's approach: by connecting with administrators instead of relying on the literature, the study avoids focusing only on institutions with the most active publication records. We wished to revisit Reave's approach while also correcting a perceived limitation: by connecting with educators directly rather than with

administrators, we hoped to also understand the unique perspectives and experiences of staff working in this niche within engineering. Thus, we aimed to move beyond the paper requirements of a programme, to more fully understand the unique contexts in which communication instruction is developed and delivered.

The path to becoming a communication or writing educator in Canada differs from many international contexts. Because there is no tradition of doctoral programmes in technical communication or engineering education in Canada (thus far we only have a few formal specialisations in the latter), engineering staff specializing in transferable competencies and skills (including communication) often come from diverse disciplinary backgrounds. Through this study, we aimed to explore the relationship between educators' disciplinary training and their approach to communication instruction, while also gathering up-to-date data about communication requirements and curricular models.

Our research consisted of three phases: (1) an initial website review to classify communication activities in each programme in Canada; (2) a follow-up survey distributed to module educators at each of these programmes; and (3) qualitative interviews with a purposive sample. We share lessons learned from this study, specifically regarding the challenge of identifying and engaging educators within this analysis.

Phase 1: website review

We began by identifying 38 English-speaking accredited Engineering programmes in Canada, as listed on the Engineers Canada website. As Engineers Canada is the licensing body for accredited engineering programmes, this website provides the most up-to-date listing of institutions and their majors. Using this list we conducted an initial website review, examining departmental homepages and academic calendars to identify required communication modules or requirements. This approach was time-consuming and often inexact. A 'search all' of engineering homepages using the search term 'communication' often yielded results from the communications office, the administrative unit responsible for advancing engineering programmes by sharing research and teaching excellence. The term 'writing' similarly yielded references to writing outreach articles (e.g. '*writing* up results'), or administrative policies (e.g. 'students must provide a request in *writing*'). These searches also turned up archived pages, meaning that seemingly relevant module-related information could be several years old.

Manually finding and reviewing 'curriculum' or 'requirements' pages for each programme — essentially following the steps undertaken by prospective students looking to familiarize themselves with programme content—provided more detailed and relevant information, but even this approach was unreliable. Different webpages from the same institution contained different types of information, and not all requirements were consistently published or kept up to date. For example, we

discovered in conversation with colleagues that one institution required students to complete several communication workshops through a non-engineering writing centre; this information was not posted on its departmental websites. Additionally, the purposes of websites are not necessarily pedagogical; rather, they are mechanisms by which institutions attract potential students and staff, and as such, are largely marketing materials. More detailed information about curriculum is often contained on internal websites or learning management systems (LMS) requiring logins, making these inaccessible to those outside the institution.

Initially, we had planned to do two things with information from these websites. First, we aimed to understand the degree of instructional integration at different schools by using Reave's 2004 taxonomy, which categorized approaches to communication instruction into electives, engineering communication centres, and integrated instruction, and further differentiated types of integrated instruction into (1) partnered curriculum development (between technical and communication specialists); (2) team teaching (again between technical and communication specialists); (3) feedback from communication specialists on individual assignments; (4) communication modules added to technical modules; and (5) writing across the curriculum methods, in which communication principles are taught throughout multiple technical modules. Second, we planned to use educator information on these websites to distribute the communication survey.

Given the paucity and inconsistency of website information, both these tasks proved difficult. Our next phase, a survey, was planned from the outset, and could fill the gaps in categorizing programmes by providing more detailed information.

Phase 2: survey

We developed a survey to capture information about the types of communication modules offered or required in engineering programmes, their learning outcomes and methods of assessment, information on their administrative oversight, specifically departmental home and instructional support, as well as the experience and interests of the educator(s). The survey was split into six sections: (1) educator information; (2) module information; (3) curriculum design; (4) instructional support and preparation; (5) assessment and feedback; and (6) future engagement. As noted above, by contacting educators directly as opposed to eliciting information from administrators as Reave (2004) did, we hoped to gain a greater understanding about the educators' position and pedagogies, as well as how their module was valued and supported within the programme.

As noted, we initially attempted to use educator information from departmental websites to distribute the survey, specifically reviewing syllabi posted online or module descriptions that included educator information. Through this method, we were able to identify some educators of both standalone and integrated modules, but educator

information was not always listed and often out of date, and syllabi were not always posted. As a result, we turned to our engineering education network for help.

We successfully obtained many more survey responses by reaching out to our contacts within the engineering communication field in Canada. We attempted to connect with at least one educator at each of the 38 institutions identified by Engineers Canada and were successful in obtaining educator responses from approximately 50% of Canadian engineering programmes. However, despite our best efforts to contact staff, even personal email requests were sometimes ignored. A stronger response may have been obtained by following Buswell et al.'s (2019) approach, contacting programme coordinators to distribute a survey to staff (however, in the one case where we did try this, we did not have success in gathering additional survey responses).

As we have discussed, a well-designed survey for this type of exercise requires a balance between eliciting rich data and respecting educator time: a shorter survey may have resulted in more responses but would have provided fewer data on programme and institutional differences, as well as educator preparation, which was of significant interest to this study. In our Canadian context, many transferable competencies and skills educators come from backgrounds outside of engineering. Understanding the variety of backgrounds of educators of engineering communication was of significant interest.

However, a major weakness of our survey may have been the significant time commitment required. The survey consisted of 30 questions, ten of which required long answers. We estimated the survey completion time to be 15 minutes, given that many answers were optional. However, the average completion time was 30 minutes. To thank participants for their time we offered gift cards of Can\$ 25, but this is arguably incommensurate compensation for such a lengthy survey.

Phase 3: qualitative interviews

While our initial intention was to complete qualitative interviews for this study after we collected survey responses, we found this phase unnecessary given the level of detail provided in the survey responses. Instead, similar to McKenzie et al. (2004), we offered an interview as an alternative for those who did not wish to complete the survey, and also invited interested participants to let us know if they wished to chat after completion of the survey. Four educators selected an interview instead of completing the survey. This approach was reasonable for our fairly small and close-knit engineering education community, in which even a higher response would have resulted in a manageable number of interviews, but would have been more difficult to conduct when trying to gather information from a larger pool.

Future work

Although the first round of survey requests took place over a year before writing this piece, we continue to invite educators within this community to share their insights

via the survey or through an interview, and to encourage participants to pass the invitation along. The snowballing nature of this approach is appropriate for a study in which the primary goal is knowledge sharing; however, the desire to make space for as many perspectives as possible delays the point at which we can share this information more widely with others who could benefit. The survey was closed in 2026, and we plan to share the data in a journal article. A summary of our results from Phase 1 are shared in Wilkinson et al. (2025).

5 Recommendations for practice

In this chapter we introduced a variety of approaches for analysing transferable competencies and skills across modules, programmes and institutions, emphasizing the importance of flexibility and adaptability in this type of comparative review. We have called attention to the lack of available landscape analyses in the literature, resulting in large part from the type of scholarship being produced in this area. The practical nature of transferable competencies and skills instruction invites action-based research: reporting on the failures and successes of discrete classroom practices or curricular innovations. Gustafsson and Jacobs (2013) argue, specifically regarding communication instruction, that a lack of landscape or meta-analyses makes arguments for skills instruction less persuasive. The fact that transferable competencies and skills instruction require justification at all is worth exploring further.

Unlike core engineering curricula, transferable competencies and skills are often treated as ancillary areas of instruction: content that is added to the curriculum, but fundamentally less important than technical curricula. This bias makes transferable competencies and skills instruction vulnerable to several factors. Transferable competencies and skills initiatives are vulnerable to budgetary stress, often being the first initiatives stripped away to save money or time. They are vulnerable to staffing changes: an integrated approach to instruction, which is highly effective in increasing perceived relevance, situates transferable competencies and skills within core technical curricula, meaning that relationship-building between the skill expert and technical expert is critical, and difficult to maintain when a module changes hands. The expertise of skills educators may be more vulnerable to scrutiny from engineering educators: because skills educators often have backgrounds in subjects other than engineering, they must work harder than their engineering counterparts to explain the strengths and theoretical underpinnings of their work. The fact that transferable competencies and skills are often taught by non-research staff also impacts the amount of available scholarship about their integration.

These influences contribute to a teaching and scholarly environment in which significant innovation is taking place, but in which this information is infrequently reviewed and reported. The practical and often inward-facing purposes of module, programme, or institutional analyses exempt these initiatives from the conventions that sometimes constrain traditional research projects but also mean fewer of these studies are published and widely disseminated, and without this reporting there may

be an assumption that transferable competencies and skills programming is often designed without a solid rationale. We can counter this misapprehension by more thoughtfully designing, conducting, and disseminating comparative reviews; this research is a valuable source of information as we make decisions about programme and module design, and also provides a valuable rationale as we share this decision-making with our engineering colleagues.

Overall, we found that for comparative reviews, the aim is crucial, and arguably more important than the research design; the scope is intentional and precise, and researchers must be curious, persistent, and adaptable in adding or changing methods to accrue more information. It is difficult work, as tracking transferable skill pedagogies in engineering is not done consistently, not all educators or administrators disseminate their work, and dissemination sites vary greatly. We recommend that as a community, we strive to better document, map, and archive the important work of teaching transferable competencies and skills and to develop more opportunities to engage in scholarly conversations. We should embrace opportunities to communicate and collaborate with other researchers and practitioners to understand how activities and curricula vary between institutions, and look for dissemination opportunities, including conferences and journal articles, to share this knowledge. In this way, we make pedagogical and curricular norms transparent and reduce the burden for other educators working to integrate transferable competencies and skills instruction. For more information on how to disseminate, see Chapter 5.6.

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AI statement

During the preparation of this work, the authors used Microsoft Copilot during the revision stage in order to generate formatting ideas for Table 1. After using this tool, the authors reviewed, edited, and made the content their own as needed. They take full responsibility for the content of the publication.

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ⁱ Big 10+ refers to the Big 10 Academic Alliance, a network of 18 leading research institutions in the United States “*dedicated to advancing the academic excellence of member institutions through national leadership, collaboration, and co-investments*” (Big Ten Academic Alliance, 2026).

ⁱⁱ The Gourman Report was a ranking of American and international undergraduate, graduate and professional programmes produced by Jack Gourman, a retired political science professor, from 1967-1998, and endorsed and distributed by the Princeton Review for their last few years (Gourman, 1998). The rankings have since been criticized for a lack of consistent and transparent evaluation criteria (Selingo, 1997).

5.6

Dissemination: Sharing Your Work and Finding Your Audience

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Having developed an intervention or innovation in your class, programme, or institution and then evaluated its effectiveness, the obvious next step is to share this practice through some form of dissemination. In this chapter we aim to support those looking to disseminate their papers in the field. We explore the various outlets that are available, in both general and specific terms. We explore online forums (blogs etc.) or more traditional outlets such as conferences or journal publications. As Engineering Education Research (EER) is an emerging field, this journey can be particularly complex and challenging, and so we give an overview of the process involved in getting an article ready to be published in education conference proceedings or in an academic journal. We aim to support authors in understanding both the publishing landscape but also particular norms in publication style that may not be identical to the technical field in which they first trained. We also look at the wide range of conferences available to those looking to present and publish their work and explore how each has their own distinct scope and specific audience.

1 Introduction

Chapter 5.6 is intended to help educators who have evaluated their teaching of transferable competencies and skills and want to disseminate the results of their evaluations. This may involve educators who have never written a paper or educators who have written papers in their own field of engineering or technical expertise but never on education. This chapter is aimed at helping them take their first steps. We will look at questions such as: what is the purpose of reporting and dissemination? Who do we disseminate for? What paths are there for dissemination of results in engineering education?

Engineering education has emerged as an independent field rapidly over the last couple of decades. Starting predominantly in the US, there are now a number of well-established departments of engineering education (for example Purdue, Virginia Tech, and the universities of Cincinnati, Buffalo, Florida, Texas at El Paso, Ohio State, and Utah State). More recently, centres have emerged in Europe (Wint et al., 2025) for example in Scandinavia, the Benelux, and the UK (Wint & Nyamapfene 2022).

As a relatively new and inherently interdisciplinary field, engineering education research and practice draws from many different disciplines and is still in the process of defining and redefining its own norms and conventions. This is evident in the range of dissemination outlets available and the challenges for all engineering educators, but for those especially newer to research and dissemination in the field, to find the appropriate venue for their work to get maximum attention.

1.1 *Why might we wish to disseminate our work?*

Arguably the first questions academics in the engineering education should ask themselves are: why do you want to disseminate your work? Who would you like it to reach? Knowing this, you are more likely to achieve your goals in sharing your work with the wider community.

While we might sometimes like to think we are simply benevolent geniuses, duty-bound to share our discoveries with the engineering education community, in reality it takes time and effort to disseminate our work. For most, while advancing the engineering education field is important, we will also want to maximise the impact of our work and achieve wider personal goals.

In disseminating your work, you may have different goals:

- Benefit students and academics beyond your own institution through their adoption or adaption of your work;
- Provide a building block to be used by the community as part of a more general evolution of engineering education;
- Act as an indicator of your personal standing in the community to support career progression;
- Test your ideas in the wider community;
- Attract collaborators and contacts;

- Influence policy either through government bodies or professional organisations.

Practical considerations will also influence your choice of dissemination route, such as:

- How much data do you have or do you need to acquire and how much research rigour can you apply to your work?
- How much time do you have to spend on researching and writing and how much time do you need to set out your story?
- How much skill do you have in shaping the narrative of your work to suit the styling, process, and expectations of the dissemination route proposed?
- How much budget do you have for costs such as conference travel and registration, open access fees for journals, and direct research costs such as consumables or participant incentives?

2 Where to disseminate your results

Dissemination of education innovations can take many forms. The ideal venue will depend on the type of work and the type of audience sought. In this section we will review education conferences, journals, and other forms of dissemination such as blogs, podcasts, and the popular media. We will discuss the merits of each, as well as discussing approaches that might be helpful in preparing and utilising these routes.

2.1 Education conferences

Education conferences are a great way to get feedback on your work and to engage in active discussion with like-minded researchers and educators. Engineering education conferences have a reputation of being welcoming and inclusive environments without the competition seen in some technical fields. They are a great way for you to meet as wide as possible an audience with a direct interest in engineering education. There is a wide range of educational conferences and networks in which engineering education developments and research can also be shared. Those listed in table 5.6.1 have a specific engineering education focus and are therefore ideal for new academics wishing to get a broad view of the field and meet with its leading proponents. There are also many broad conferences that have an element of education included, either discipline-specific conferences with an education track or conferences covering education across STEM subjects or beyond. The ones suggested here are linked to international organisations with a specific focus on education or engineering societies (sometimes also referred to as professional engineering institutions) which organise a specific education conference, but the list is by no means exhaustive. They range in scale from REES (typically 80-100 people) to ASEE, which welcomes over 4000 participants every year, with the SEFI annual conference sitting in between at 500-600 people attending.

In addition to these, most countries will have localised networks who run their own symposiums or conferences, e.g., the UK & Ireland Engineering Education Research Network (EERN) and the Engineering Professors Council in the UK; or the Dutch education-wide conferences on challenge-based learning and National

Interdisciplinary Education conference. If your work is potentially applicable beyond just engineering, you may want to seek a broader audience by considering conference in the wider STEM education community.

Table 5.6.1: Suggestions of engineering education conferences

<i>Name</i>	<i>Location</i>
SEFI Annual Conference	Europe
CDIO Annual Conference & Regional Meetings	Worldwide
American Society for Engineering Education (ASEE)	US & Canada
Australasian Association for Engineering Education	Australasia
World Engineering Education Forum	Worldwide
Research in Engineering Education Symposium (REES)	Worldwide
IEEE Frontiers in Education	Usually US
ASME Mechanical Engineering Education (MEEEd)	Usually US

While most conferences implement rigorous peer review processes to ensure submissions meet appropriate quality standards, they often adopt a more flexible approach than journals. This flexibility allows for the presentation of work in progress or practice-based experiences, particularly in cases where formal research methodologies could not be applied. However, as conferences typically run annually, it is important for authors to be aware well in advance of submission timelines to ensure their work will be ready at the correct time to allow for consideration.

In addition to showcasing education research and teaching practices, conferences provide academics with valuable opportunities for direct, in-person feedback and the chance to establish new collaborations. The flexibility to present work in various formats — such as posters, roundtables, traditional papers, practice papers, and interactive workshops — allows you to choose the most effective method for communicating your findings and maximizing the impact of your work.

2.2 Journal publication

To reach the widest audience possible, you may seek a journal publication for your research output. While perhaps the most broadly recognised and valued form of dissemination — especially to research-oriented promotion panels and tenure review boards — they can also be the slowest and most daunting outlet. One of the first hurdles to cross is identifying which journal might be appropriate. Although many journals have similar titles, they often have very distinct remits and scopes. Before approaching any journal, it is important that you consider the journal scope carefully to ensure that your work will not be immediately desk-rejected (i.e. rejection prior to being sent for review) by the editor-in-chief (EiC) — or worse, held in the queue for some time before being rejected for being out-of-scope. In particular, look out for scopes that specify relevance to a particular region, a particular engineering discipline,

or a specific theme within engineering education. We have divided the key journals available into five distinct categories depending on their scope, which may help authors to select the appropriate type of journal.

General EER journals

General EER journals accept papers across a wide range of topics within engineering education research. They accept qualitative, quantitative, and mixed methods studies and all have an emphasis on the rigour of the research methodology underpinning the studies. A selection of the key general coverage journals is provided in Table 5.6.2.

Table 5.6.2: General-coverage engineering education journals and their scope (partially based on REEN, n.d.).

<i>Journal title — Publisher</i>
<u>Engineering Education Review</u> — Scholar Media Publishing <i>This new journal publishes critical analysis, summary, and evaluation of previous research to expand new perspectives, to guide paradigm shifts in engineering education, and to improve academic discourse and practice systems.</i>
<u>International Journal of Engineering Education (IJEE)</u> — Tempus Publications <i>Independent, peer-reviewed journal which accepts regular papers and special issues with a focus on engineering education.</i>
<u>International Journal of Engineering Pedagogy (IJEP)</u> — International Federation of Engineering Education Societies (IFEES) <i>An independent, peer-reviewed online journal. Educators and researchers as well as schools and institutions are invited to discuss their research, experiences, ideas, and perspectives in the field of engineering pedagogy.</i>
<u>Studies in Engineering Education (SEE)</u> — VT Publishing <i>International, open-access, peer-reviewed journal that provides a venue for high-quality research conducted in all settings and contexts relevant to engineering education, with an emphasis on contextually rich reflective discussions of issues and approaches important to engineering education researchers and practitioners.</i>
<u>International Journal of Technology and Design Education</u> — Springer <i>This journal publishes research on all aspects of technology and design education. It features critical, review, and comparative studies addressing technology and design education and includes papers that draw from various fields such as history, philosophy, sociology, and psychology.</i>

Table 5.6.3: Regionally focused engineering education journals and their scope (REEN, n.d.).

<i>Journal title — Publisher</i>
American Journal of Engineering Education (AJEE) — Clute Institute <i>Publishes articles that bridge the worlds of theory and practice, identify cross-disciplinary and cross-institutional innovation, and describe educational strategies to address the changing role that engineering plays in society and in driving economies.</i>
Australasian Journal of Engineering Education (AJEE) — Taylor & Francis/AARE <i>Papers report research that makes an original contribution to knowledge and can be used to improve engineering education by informing practice, policy, and/or research. Contributions must be relevant to readers in Australasia and/or internationally.</i>
ASEAN Journal of Engineering Education (AJEE) — Universiti Teknologi Malaysia <i>Publishes papers that bridge the world of theory and practice in engineering education. There are two sections in the journal: the first focuses on rigorous research on engineering education, while the second includes papers that offer scholarly experience on practice and innovation in engineering education strategies.</i>
European Journal of Engineering Education (EJEE) — Taylor & Francis/SEFI <i>The journal embraces multiple perspectives to examine relevant conditions, developments, approaches, methods and experiences relevant for higher education in engineering. It is a European journal with global readership and authorship. While the European context is emphasised, papers presenting wider international or intercultural dimensions are also considered for publication. It invites relevant contributions that combine scholarliness with usefulness for improving engineering education.</i>
Journal of Engineering Education (JEE) — Wiley and Sons <i>Publishes original research that contributes significantly to the body of knowledge in the field of engineering education. Managed by the American Society for Engineering Education, JEE accepts empirical investigations, research reviews, and other types of papers.</i>
Southern Journal of Engineering Education (SJEE) — South African Society of Engineering Education (SASEE) <i>While critical perspectives from the Global South are the main interest, papers that deal with wider international or intercultural dimensions, of interest to our readership, are also considered for publication.</i>

Regionally focused journals

These journals are very similar to the general EER journals above but are typically associated with a regional engineering education association. Because of their affiliation to a regional society, they tend to have an emphasis on studies that are directly relevant to readers from that region. That certainly does not mean that they will not accept papers from authors outside the region; however, work that is specifically focusing only on a different region — e.g., a Chinese specific study submitted to a European journal — may be considered out of scope. These journals are typically associated with a regional engineering education association. This affinity to a regional group of research often means that journals are highly visible in that community. Again, some of the most high-profile are outlined in Table 5.6.3.

Practice-focused journals

Recent years have seen the emergence of practice-focused journals, with two such examples provided here (Table 5.6.3). While still expecting a level of rigorous evaluation, there is an emphasis on the description of the practices and/or the pedagogic principles behind them to ensure that innovations can be adopted rapidly and readily by other practitioners.

Table 5.6.3: Practice-focused engineering education journals and their scope (partially based on REEN, n.d.).

<i>Journal title — Publisher</i>
Advances in Engineering Education (AEE) – ASEE <i>The journal aims to disseminate significant, proven innovations in engineering education practice, including those that are enhanced through the creative use of multimedia.</i>
SEFI Journal of Engineering Education Advancement (SEFI-JEEA) — European Society of Engineering Education (SEFI) <i>The journal welcomes appropriate submissions of innovations in practices, approaches, or ideas within the field, which will appeal and be useful to practitioners as well as researchers.</i>

Special topic area journals

This subset of engineering education journals takes a particular focus on an aspect of engineering education. If your work falls within these areas, they offer an excellent opportunity to position your manuscript in the context of similar work in that area and to receive feedback during the review process from highly knowledgeable peers in this specific area. Table 5.6.4 provides a selection of these.

Table 5.6.4: Special topic area engineering education journals and their scope (partially based on REEN, n.d.).

<i>Journal title – Publisher</i>
Journal of International Engineering Education (JIEE) — University of Rhode Island <i>Serves as a unique peer-reviewed resource for academic, corporate, non-profit, and other constituencies involved in creating, maintaining, growing, and studying international engineering education programmes.</i>
Journal of Pre-college Engineering Education Research (J-PEER) — Purdue University Press <i>Disseminates original scholarly articles that seek to investigate, enhance, and transform pre-college engineering education.</i>
Journal of Women and Minorities in Science and Engineering (JWM) — Begell House <i>Publishes original, peer-reviewed papers that report on empirical investigations covering a variety of topics related to achieving inclusion of historically underrepresented and minoritized populations in science and engineering education, academia, and professional practice. These populations include those who identify as people of colour, women, first-generation college students, veterans, members of the LGBTQ+ community, people with disabilities, and the intersections of these and other identities.</i>
Engineering Studies — Taylor & Francis <i>Publishes critical analysis in historical, social, cultural, political, philosophical, rhetorical, and organizational studies of engineers and engineering. The journal takes an interdisciplinary approach to understanding the culture and practice of engineering (broadly construed), with the interdisciplinary field of Science and Technology Studies as a foundation.</i>

Engineering discipline-specific focus journals

Many of the discipline-specific technical societies also offer an educational publication within their journal portfolio. For work that has elements that situate it within a specific engineering discipline, these can be highly appropriate publications venues and offer wide exposure for the work with educators in a given field. Historically, the alignment with highly technical publications has meant that quantitative research has been favoured, but this has changed in recent years. It is important to read the scope of these journals very carefully, as they will have very clear boundaries for what is in and what is out of scope.

Table 5.6.5: Examples of discipline-specific engineering education journals and their scope (partially based on REEN, n.d.).

<i>Journal title — Publisher</i>
<u>IEEE Transactions on Education</u> — Institute of Electrical and Electronics Engineers (IEEE) <i>Publishes contributions to education in electrical and electronics engineering, computer engineering, computer science, and other fields within the scope of interest of IEEE. Contributions must address discovery, integration, and/or application of knowledge in education in these fields.</i>
<u>Journal of Civil Engineering Education (JCEE)</u> — American Society of Civil Engineering (ASCE) <i>Publishes on a wide range of subjects within civil engineering education, with a special focus on connecting engineering and construction education to professional practice. Papers examine research on effective methods to teach engineering and construction principles and prepare students to succeed in practice, with emphasis on the engineer's and constructor's professional obligations and responsibilities.</i>
<u>Chemical Engineering Education (CEE)</u> — ASEE, Chemical Engineering (ChE) division <i>Expects papers focussing on teaching chemical engineering, ChE curriculum and courses, ChE students, or the future of the field.</i>
<u>Biomedical Engineering Education</u> — Springer <i>Publishes on practice and scholarship of education in bioengineering, biomedical engineering, and its allied fields.</i>
<u>Computer Applications in Engineering Education (CAEE)</u> — Wiley <i>Focuses on innovative uses of computers, internet, and software tools in engineering education.</i>
<u>Journal of Materials Education</u> — International Council on Materials Education <i>Publishes on education in materials science and engineering, including pedagogical and technical subject areas, new materials, new characterization procedures, new processing techniques, and strategic development of education programmes.</i>
<u>Education for Chemical Engineers</u> - Elsevier/Institution of Chemical Engineers <i>Targeted at chemical engineering academics and educators, discussing the ongoing changes and development in chemical engineering education.</i>

Broad educational journals of interest to EER

Table 5.6.6 lists examples of journals outside of the EER sphere, which will commonly published EER research if it fits certain criteria. Some, for example the *International*

Journal of Sustainability in Higher Education, will publish higher education research from any field as long as it related to aspects of sustainability. The other publications are general higher education research journals and are often good publication venues for work that may have influence beyond engineering, for example work on education development or those that relate to curriculum development or educational policy.

Table 5.6.6: Examples of educational journals that publish engineering education research and their scope.

Journal title — Publisher

International Journal of Sustainability in Higher Education — Emerald Publishing

Publishes papers relating to sustainability in a higher education context.

Journal of Cleaner Production — Elsevier

Focuses on cleaner production, environmental science, and sustainability research and practice. Regularly publishes education papers in this area.

Journal of Problem Based Learning in Higher Education — Aalborg University Open Publishing

Publishes research articles and cases on problem-based learning with a focus on higher education.

Studies in Higher Education — Taylor & Francis

Publishes research-based articles dealing with higher education issues from either a disciplinary or multi-disciplinary perspective. Empirical, theoretical, and conceptual articles of significant originality will be considered.

Higher Education — Springer Nature

With a diverse range of authoritative overview articles, comparative studies, and focused analyses, the journal aims to deepen our understanding of higher education across the world.

International Journal of Educational Research — ScienceDirect

Publishes high-quality research that advances our understanding of education, learning, and development across all educational stages and diverse international contexts. The journal serves researchers, practitioners, and policy makers, providing a platform for rigorous, relevant, and impactful studies

Research in Science & Technological Education — Taylor & Francis

An original research journal publishing international perspectives on science and/or design technology education. Focuses on scholarly research that investigates and interrogates the psychological, sociological, economic, and organisational aspects of science and design technology education, as well as developments within the global curriculum.

2.3 Other forms of dissemination

While peer-reviewed journals and conferences often carry the most kudos in academic circles, if the primary aim is to disseminate your work as widely as and as quickly as possible, they may not provide the most compelling outlet. These outlets may be found in the digital world. One of the key advantages of emerging digital formats — such as blogs, podcasts, and video channels — is their ability to incorporate mixed media to enhance communication and engagement. However, unlike traditional journals, which benefit from established systems of archiving and discoverability through specialist search engines, these newer dissemination methods often require authors to be more direct and proactive, using social media and personal networks to ensure they are able to reach and grow their audience. Such approaches, that are gaining in popularity and should be considered, include the following.

Academic and professional platforms. There are now a wide range of preprint servers (e.g., arXiv, SSRN, bioRxiv) as well as social networks for researchers, such as ResearchGate and Academia.edu, that allow work to be shared and enable discussion and engagement with peers. It is not uncommon to see unpublished papers made available through these platforms or even institutional repositories being publicised through these networks as a form of dissemination. You may also consider dissemination via LinkedIn. While this is not a suitable place to publish full papers, it does offer the opportunity for short vox pops, innovation snippets or adverts/pointers for the full publication. It also has the social media options to like, share, follow, and comment, thus contributing to network building.

Blogs and personal websites. These informal platforms allow dissemination and commentary on research findings and allow practitioners to showcase the innovations they have made in the classroom.

Podcasts and YouTube channels. Using audio-visual formats is one of the most powerful ways to demonstrate education innovations to a wider audience, especially when coupled with the use of social media, for example LinkedIn, to alert peers to a new video.

Popular media articles. As originally print-based publications moved online, the use of guest articles or blogs has increased substantially, offering the opportunity to spotlight all aspects of teaching innovation. Popular outlets with a higher education focus include *Times Higher Education*, *Wonkhe* (for research with policy implications), the *Chronicle of Higher Education* and *The Conversation*. In addition, engineering stories are often carried by tech-focused media such as *Wired*, *TechCrunch*, *The Verge*, professional magazines such as *The Engineer*, or society magazines such as *IEEE Spectrum* or IET's *E+T* magazine.

Books. Specialist academic books in engineering education continue to be published, typically in the form of handbooks or guides designed to support practitioners in specific areas of the field. To manage the workload, these volumes are often collaborative efforts involving multiple authors. As structured guides, their content is

usually predefined by the book or series editors, making them less suitable for more open or exploratory forms of dissemination.

Reports or position papers. Academic engineering societies or groups may commission reports or publish position papers. These allow academics to work with like-minded individuals on specific topic areas, often with the goal of influencing future direction of an aspect of education.

3 How to disseminate your results

In this section, we discuss the typical build-up of dissemination, including how each type of publication is typically structured.

3.1 Popular media, blogs, and websites

Getting research or educational innovations published in popular media — like newspapers, magazines, blogs, or podcasts — requires a different approach than academic publishing. Content must be engaging to a broader readership than academic work. One approach is to use storytelling to frame your research — what problem does it solve? Why should people care? How does your work impact society, technology, or daily life for engineers or engineering students? For these mediums it is important to be clear and jargon-free in your writing, replacing technical terms with analogies, concrete examples, and everyday language.

Although you can create your own website or blogs, gaining an audience can take considerable time and effort and if you choose to do so it might be more productive to collaborate with established channels, especially those focused on engineering, innovation, or science communication. Recognised platforms or university supported blogging sites are recommended, such as *Medium* or *Substack*.

An alternative is to target platforms that align with your topic and audience to disseminate your work. The greatest impact is found in general science outlets such as *Scientific American*, *New Scientist*, *Quanta Magazine* or mainstream media with science and engineering sections such as *The Guardian*, *The New York Times* or *BBC Future*; however, these are also the most challenging to penetrate. With the increase in the level of output in the online era, there is an opportunity to pitch an idea for a story to an outlet's online editor. University press offices are typically well connected to such publications and are usually happy to advise on the best approach to maximise exposure for the university. Ultimately, the nature of the content production cycle means that most content needs to be relevant at a specific moment and therefore there is often an element of opportunism needed to get your innovation published through these channels.

3.2 The publication process

While most academics will be familiar to some extent with the norms of academic writing, there are some important areas to consider when developing an output for an EER journal.

What is important in the paper?

Title. First of all, the title is important! As journals have shifted from print to online, the concept of 'reading' a journal as one might a monthly magazine has shifted. Publishers have noticed that most articles are found via search engines rather than through scouring a particular source. For most articles this means that the title (and perhaps abstract) must have 'Google juice'. This is particularly true for articles behind paywalls (i.e., non-open access). Think carefully about what terms your intended audience might be searching for and make sure they feature prominently.

Abstract. This is your opportunity to sell the work; here you need to give enough detail (within the space allowed) to make your reader want to read on. Again, for paywalled articles this might be all that is available without a subscription, so the abstract needs to describe the novelty of the work and why it might have significance or interest to others but should also provide brief details of methodology and context (e.g., is this a study in one institution or many?). A good abstract is clear, avoiding imprecise or ambiguous language, abbreviations, or acronyms, and does not include citations or hyperlinks. It also should use the active voice: "*We undertook a study to...*". While it is important to engage readers to want to read on, do not exaggerate and oversell the results of the work. Some journals use structured abstracts to help format this information. This might ask you to provide two or three sentences on each the following: background, purpose, methodology, results, and conclusions.

The body of most journal papers follow variations on a similar pattern.

Introduction section. This provides the background and context of the work. It should explain in some detail the research question that the work is looking to answer. It may also survey the 'related literature' or 'state of the art' in order to show how the author's work can be positioned in the existing knowledge, or to underpin the research question.

Methodology/method. This explains the process used to address the research question. The methodology justifies the approach, often including the theoretical framework, while the method provides the detail about data collection and analysis. It details the overarching strategy, specific techniques, and procedures used to collect and analyse data (Case & Light, 2011). It is important to be quite detailed here. For example, in a study involving a survey, discuss: how were participants selected? How where they contacted? How many and what proportion responded? How was the survey developed? What theoretical framework was used to analyse the data? For some types of studies, rigorous protocols have been developed, for example for systematic literature reviews (Borrego et al., 2015). If used, these should be referenced. If you have followed the framework of EER presented in Chapter 5.1, then you should be well positioned to provide all the detail a reader would need to understand the process of your study.

Results and analysis. The main aim here is to present your findings clearly, neutrally, and aligned with your research questions or hypotheses. This section typically includes descriptive statistics and reliability and validity metrics for instruments for quantitative

work, or themes, categories, or codes from interviews, as well as reflections, open-ended questions, or representative quotations for qualitative works.

Discussion and conclusions. The most important thing here is to not oversell the results. Nothing attracts a reviewer's wrath more than trying to overgeneralise the results beyond the scope of the data set. This can be a good point to include a thoughtful section on the limitations of the study.

Check if any declarations are needed at the end of the paper or in the submission system. This might include:

- *Acknowledgements.*
- *Author contributions.* This lists which of the authors made which contribution, from conceptualising the idea for the study, to collecting the data, to writing the paper. Some journals have very specific requirements for this while others use the CRediT (Contributor Roles Taxonomy) statement, such as this handbook (NISO, n.d.).
- *Source of funding.* How was the work funded;
- *Ethical approval.* This is typically required for all studies that interact directly with people;
- *Conflicts of interest.* This should mention any financial, in-kind support, professional, personal, or other relationships that could influence or be perceived as influencing the research or judgement.
- *Use of artificial intelligence.* This section should state which large language models and machine learning tools, if any, have been used in collecting and analysing the data or in writing the paper;
- *Data availability statement.* Increasingly, journal publishers are asking for the data set on which the research is based to be made available for others to review and potentially to reinterpret. This is yet to become widespread in education research, due to anonymity and ethical concerns.

Submission process

Although there are many common features to the submission process, each journal will have its own peculiarities. All journals will have an 'information for authors' section or similar. Spending some time reading through the guidance could save a lot of time later on. A few things to look out for:

- *Does the journal require a particular format for peer-review?* Many allow unformatted submissions, but some require the paper to be put into the journal's template at first submission — often to ensure page limits are met.
- *Does the journal require a specific form of abstract?* Structured abstracts — divided into specific sections rather than just one chunk of text — are required by some journals.
- *Does this journal have page limits?* Some will accept papers over the limit but charge a fee for overlong papers. Best to be aware of this ahead of submission.
- *Do you have details of the ethics review and your data protection policy?* This can be asked at the submissions stage. If you are using human subject data

(which much education research does) this should usually receive Ethics Review Board (or similar) clearance prior to the study taking place.

- *Do you need to highlight specific aspects in a cover letter to the editor-in-chief?* This might include whether some of the results have already been published in conference papers. Most journals allow some amount of reuse as long as new results are included, but flagging this in the cover letter (which may be a formal letter or may be just a text box in the submission) is helpful, rather than the editor finding out when plagiarism alerts start appearing in the system (most journals use plagiarism detection software to highlight content reuse).
- *Is the journal single- or double-blind review?* Both exist within the journals listed above. For double-blind review (where reviewers don't know the authors and authors don't know the reviewers) all identifying features must be removed from the text. This includes references to the institution or citations that will obviously reveal the authors. For single-blind processes (where the reviewers are aware of the authors' identity) this is not necessary.

Review process

Again, while there is no universally standard process, most journal follow a similar process.

1. The publisher undertakes a basic screening. This is usually just tick-box on adherence to key measure — not overlength, appropriately blinded for review, in correct format etc.
2. The editor-in-chief and/or an associate editor (or guest editor if a special issue) performs a basic review. This is a check, firstly, to see if the paper is within the scope of the journal, but also to confirm that there is a possibility that the paper will receive a positive review. This may confirm that there are sufficient results or that the research question and research methodology are adequately described. If rejected at this stage, this is what is called a desk-reject. You should remember that ultimately it is in the journal's best interests to publish papers, but also that there are limited reviewer resources available (ask any EiC about the difficulty in finding reviewers and you will get the idea!).
3. Assuming these thresholds are met, the paper will be sent out to reviewers. These are selected usually by the associate editor assigned to your manuscript, as experts related to the field of your paper. They will be given a fixed time period to return the review. This process can take from a couple of weeks to many months (most try to limit this but not always successfully!). The number of reviews required will depend on the journal. Many aim for at least three, but will accept two good reviews if necessary.
4. Once the required number of reviews is reached, the manuscript will be returned to the associate editor for a recommendation, based on the information provided by the reviewers.
5. This recommendation is passed to the EiC, who ultimately makes the decision on what will happen to the paper. The categories will differ between journals, but some common responses included:

- a. *accept* — the paper is accepted without revisions. It is now ready for proofing and typesetting for publication. For most journals, it is unlikely that you will receive this response after the first round of reviews.
- b. *minor revisions* — a few modifications or corrections must be made before the paper is ready for publication. After revision, these will often be signed off by the associate editor without the need for the reviewers to comment on the paper again.
- c. *major revisions* — revisions are needed that require more time or which are more fundamental. The paper will usually go back to the original reviewers (if possible) for re-review when re-submitted.
- d. *reject with resubmission* — while there is potential for publication, there is too much work required for a resubmission within a reasonable timeframe. Examples are papers that require the collection of more data or significant reanalysis of data before they can be considered again.
- e. *reject* — it is judged that the paper will not be publishable by this journal.

It is not uncommon for papers to go through two or even three rounds of review before reaching acceptance.

4 Final thoughts

There is a vast array of possible outlets for engineering education innovations; the right one depends on the type of work and the desired audience. Many of these avenues might seem daunting, with vague rules and norms. This chapter has aimed to shed some light on possible approaches to dissemination and some of the processes behind academic publishing. When starting out it can at times feel like the system is there to stop your work getting published, but you should remember that ultimately editors, whether of media outlets or journals, need content. Therefore, it is their job to support authors to produce papers or articles that their readership wants to read. Sometimes they do this by dispensing the harsh truth that a particular piece of work is not right for them (remember, it is just not for them — other venues may take a different view), but also, often, by advising authors on how to make the most of their work and how to get it ready for publication. By engaging with the community, for example, you will find many of the editors-in-chiefs of the major journals at conferences such as ASEE or SEFI. This will give you the opportunity to adapt your work to the dissemination outlet of choice.

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AI statement

During the preparation of this work the authors did not make use of any AI tools.

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Back Matter

Glossary

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This chapter contains an alphabetical overview of all relevant terms and abbreviations used in the SEFI Handbook for Teaching Transferable Competencies and Skills in Engineering, their definitions, and where possible, their source, explained within a European education context. It aims to aid the reader in quickly accessing definitions for the most important terms used in this handbook.

ABET A non-profit USA-based organization that accredits college and university programmes in applied science, computing, engineering, and engineering technology. Known under the full name of Accreditation Board for Engineering and Technology until 2005 (ABET, 2005).

Academic staff Members of staff at a higher education institution that are primarily concerned with teaching and research and usually hold a degree themselves. In North America often referred to as faculty.

Accessibility *"The provision of flexibility to accommodate each user's needs and preferences; when used with reference to persons with disabilities, any place, space, item or service, whether physical or virtual, that is easily approached, reached, entered, exited, interacted with, understood or otherwise used by persons of varying disabilities, is determined to be accessible"* (United Nations, 2013, p. 3).

Accreditation *"The process by which a (non-)governmental or private body evaluates the quality of a higher education institution as a whole or of a specific educational programme to formally recognise it as having met certain pre-determined minimal criteria or standards. The result of this process is usually the awarding of a status (a yes/no decision), of recognition, and sometimes of a license to operate within a time-limited validity. The process can imply initial and periodic self-study and evaluation by external peers"* (Vlăsceanu et al., 2007, p. 25).

Accreditation standards see Programme outcomes.

Action Research (AR) Also referred to as 'practitioner research' or 'inquiry-defined research', meaning *"any systematic inquiry conducted by teachers, administrators, counsellors or others with a vested interest in the teaching and learning process or environment for the purpose of gathering information about their particular school's operation, how they teach and how their students learn. It is done by teachers for themselves as a systematic inquiry into their own practice"* (Mertler, 2024, p. 7).

Active listening *"Empathic responding using both words and actions, based on understanding the speaker's idea, attitude, and point of view, so that the listener senses how it feels to the speaker and grasps the speaker's frame of reference about the subject"* (Novick et al., 2021, p. 1).

Adaptability for change or change management A learner's adaptability involves identifying *"qualities which are critical for future performance and being both willing and able to make personal changes in order to meet those needs in a proactive way"* (Hall, 2002, in Hall & Chandler, 2005, p. 163).

AHSS Arts, Humanities, and Social Sciences.

Assessment The process used to evaluate the learner's progress and ascertain the achievement of the learning outcomes of an educational component (unit/module) using methods such as written, oral, and practical tests, examinations, projects, performances, presentations and portfolios (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2015).

Autonomous motivation A synonym for intrinsic motivation, which refers to doing something because it is inherently interesting or enjoyable, or motivating oneself by focusing on positive external factors (Ryan & Deci, 2000).

Case study A case is “*a thing, a single entity, a unit around which there are boundaries*” (Merriam, 1998, p. 27 in Yazan, 2015) and can be a person, a program, a group, a specific policy, etc. A qualitative case study is “*an intensive, holistic description and analysis of a bounded phenomenon such as a program, an institution, a person, a process, or a social unit*” (p. xiii). There are different types of case studies: particularistic, i.e., focusing on particular situation, event, program, or phenomenon; descriptive, yielding a rich, thick description of the phenomenon under study; and heuristic, illuminating the reader’s understanding of a phenomenon under study.

Chartered Engineer A professional status granted by a recognised engineering body indicating the highest level of competence and expertise. Chartered Engineers are formally registered engineers who develop solutions to engineering problems using new or existing technologies, through innovation, creativity, and change, and often take technical responsibility for complex systems (The Institution of Engineering and Technology (IET), n.d.).

Collaboration A joint effort by multiple people towards a group goal (Briggs et al., 2006).

Constructive alignment An education design model based on a combination of constructivist theory and aligned instruction, in which teaching and learning activities and assessment tasks are in alignment with the intended learning outcomes to allow for deep engagement (derived from Biggs & Tang, 2011).

Continuous Professional Development (CPD) “*Formal in-service training undertaken by teachers or higher education staff throughout their career that allows them to broaden, develop and update their knowledge, skills and attitudes. It includes both subject-based training and pedagogical training. Different formats are offered such as courses, seminars, peer observation and support from networks of practitioners. In certain cases, CPD activities may lead to supplementary qualifications*” (European Commission: European Education and Culture Executive Agency, 2024, p. 217).

Course A course may be a self-contained, formally structured learning experience with learning outcomes, but is used interchangeably with *seminar*, *lecture*, *classroom activity*, *MOOC*, *subject*, *module*, or even *programme* (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2015). As the word *course* is ill-defined, in this handbook we use the word *module* for a self-contained, formally structured, credit-giving component of a programme, usually covering a specific topic or theme, and the word *programme* to refer to a degree programme.

Curriculum The design, organisation and planning of programme activities, content and teaching of the elements that make up a programme, including the content to be covered, intended learning outcomes, and the teaching and assessment methods (Cedefop, 2024; European University Association, 2020).

Design Research (DR) In this handbook, Education Design Research refers to *“design and develop an intervention (such as programs, teaching-learning strategies and materials, products and systems) as a solution to a complex educational problem as well as to advance our knowledge about the characteristics of these interventions and the processes to design and develop them, or alternatively to design and develop educational interventions (about for example, learning processes, learning environments and the like) with the purpose to develop or validate theories”* (Plomp, 2013, p. 15).

Disability *“An umbrella term for physical, mental, or sensory impairments that, in interaction with environmental or societal barriers, limit a person’s ability to participate fully in activities. In other words, disability arises from the mismatch between individual functional impairments and inaccessible environments and thus is ‘not just one health problem’ but a complex phenomenon reflecting the interplay between a person’s condition and society”* (World Health Organization, n.d.).

Discipline-based education research *“An empirical approach to investigating learning and teaching that is informed by an expert understanding of disciplinary knowledge and practice”* (National Research Council, 2012, p. 11).

Dublin Descriptors *“[T]he cycle descriptors (or ‘level descriptors’) presented in 2003 and adopted in 2005 as the Qualifications Framework of the European Higher Education Area. They offer generic statements of typical expectations of achievements and abilities associated with awards that represent the end of each of a (Bologna) cycle or level. The descriptors are phrased in terms of competence levels, not learning outcomes, and they enable to distinguish in a broad and general manner between the different cycles. A level descriptor includes the following five components: 1) knowledge and understanding, 2) applying knowledge and understanding, 3) making judgements, 4) communication, 5) lifelong learning skills”* (European Commission Directorate-General for Education, Youth, Sport and Culture, 2015, p. 69).

EAFSG EUR-ACE Framework Standards and Guidelines (ENAE, n.d.).

Equity, Diversity, and Inclusion (EDI) Principles and practices ensuring that all individuals, especially those from historically underrepresented or marginalized groups, are valued and treated fairly. Diversity means the presence and representation of varied identities, perspectives, and backgrounds; equality (or equity) means providing fair treatment and equal opportunity to achieve outcomes; and inclusion means creating environments where everyone has a voice, feels respected, and can participate fully (Health and Care Professions Council, 2020).

European Credit Transfer System (ECTS) The system used by members of the European Higher Education Area (EHEA) to express *“the volume of learning based on the defined learning outcomes and their associated workload. 60 ECTS credits are allocated to the learning outcomes and associated workload of a full-time academic year or its equivalent, which normally comprises a number of educational components to which credits (on the basis of the learning outcomes and workload) are allocated. ECTS credits are generally expressed in whole numbers”* (European Commission,

Directorate-General for Education, Youth, Sport and Culture, 2015, p. 10). Table G.1 shows an overview of how credits from various parts of the world relate to each other using student workload.

Table G.1: Comparison of student workload expectations per credit for EHEA, UK, USA, Canada, and Australia (created by Nathans-Kelly)

<i>System</i>	<i>Credits per year</i>	<i>Student workload per credit</i>	<i>Notes</i>
EHEA	60 ECTS	20-30 hours	Used to standardise credits across EHEA.
USA	~30 credit hours	~45 hours	Focus on contact hours; varies per university and module type. 1 credit hour $\approx$ 1h contact + 2h independent study per week
UK	120 CATS	10 hours	2 UK CATS = 1 ECTS
Canada	~30 credit hours	~45 hours	Similar to USA
Australia	48 credit points	~25 hours	Varies per university; 1 CP $\approx$ 1 ECTS in some universities

Educational Design Research (EDR) “A genre of research in which the iterative development of solutions to practical and complex educational problems also provides the context for empirical investigation, which yields theoretical understanding that can inform the work of others” (McKenney & Reeves, 2018, p. 7).

Educational intervention An action, process, tool or event designed to promote learning. Examples include workshops that teach certain skills, restructuring a module to include lab sessions, teaching or instructional methods such as project-based learning, or revising the recruitment profile of teachers to require more industry experience.

European Higher Education Area (EHEA) A collaborative effort by 49 European nations, building on the main objective of the Bologna Process to create a more comparable, compatible, and coherent higher education system in Europe (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2015).

European Network for the Accreditation of Engineering Education (ENAE) A non-profit network of agencies promoting quality engineering education, primarily by authorizing accreditation bodies to award the EUR-ACE label (ENAE, n.d.).

Engineering Council The regulatory authority in the United Kingdom responsible for establishing and upholding globally acknowledged benchmarks of professional competence and ethical conduct of engineers, which also governs the award,

awarding, and retention of the titles of Chartered Engineer as well as other titles such as Incorporated Engineers and Engineering Technician (Engineering Council, n.d.).

Engineering Education Research (EER) The field of disciplinary educational research focused on generating knowledge to define, understand, and improve how engineers are educated, encompassing research on pedagogy, assessment, diversity, policy, and learning (Loui & Borrego, 2019).

Engineers Europe A federation of national professional bodies representing engineering in European countries, formally known as the Fédération Européenne d'Associations Nationales d'Ingénieurs (FEANI) (Engineers Europe, 2022).

Epistemology The philosophical study of knowledge and knowing, that concerns the nature and justification of human knowledge (Hofer, 2001; Hofer & Pintrich, 1997).

EUR-ACE A European quality label authorised by ENAEE to professional engineering institutions who accredit engineering programmes (ENAEE, n.d.).

European Qualifications Framework (EQF) An eight-level, learning outcomes-based framework for all types of qualifications that serves as a translation tool between different national qualifications frameworks within the EHEA. EQF-level 6 is typically a bachelor degree, EQF level 7 typically refers to a master degree and EQF-level 8 to a PhD degree, also known as a doctorate (Cedefop, 2024).

Evaluation In education, this term refers to "*the systemic process of assessing the effectiveness and quality of educational programmes, teaching methods and student learning outcomes*" (UNESCO, 2026). In relation to student learning, it is often the point where a student's achievement is measured for validation purposes.

Evidence-based education The principle that education practices should be based on the best available scientific evidence, with randomised trials as the gold standard of evidence, rather than tradition, personal judgement, or other influences (Hargreaves, 1996).

Evidence-informed teaching "*A complex, situated professional practice that draws on a range of evidence and professional judgment, rather than being based on a particular form of evidence*" (Coldwell et al., 2017, p. 5).

External examiner Someone from outside a student's own school, college, or university who judges an exam (Cambridge Dictionary, 2025a).

Facilitation "*The provision of opportunities, resources, encouragement and support for the group to succeed in achieving its objectives, and to do this through enabling the group to take control and responsibility for the way they proceed*" (Bentley, 1994, p. 12).

Faculty In North America, this term is used to refer to "*the people who teach in a university, college, or US high school, or in one of its departments*", whereas in Europe the term is used to refer to "*a group of departments in a university or college that specialize in a particular subject or group of subjects*" (Cambridge Dictionary, 2025b).

In this handbook, we will avoid the use of the term *faculty* to refer to people and use the term *academic staff* instead.

Feedback *"A process through which learners make sense of information from various sources and use it to enhance their work or learning strategies"* (Carless & Boud, 2018, p. 1315).

Feedback literacy skills *"[T]he understandings, capacities and dispositions needed to make sense of feedback information and use it to enhance work or learning strategies"* (Carless & Boud, 2018, p. 1316).

First-cycle degree (FCD) The first step in the higher education degree cycle under the standardized EHEA framework for learners who have completed upper secondary education or equivalent. This is typically a bachelor level programme, lasting 3-4 years, requiring 180-240 ECTS to complete (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2015; European Higher Education Area, 2018).

Framework In the context of this handbook, a framework is defined as *"a foundational structure — comprising concepts, theories, beliefs, or sets of rules — used to organize ideas, guide research, or plan curricula and instruction"* (Mccomas, 2014, p. 42).

Graduate A learner who has completed all programme deliverables and has been awarded a degree.

Graduate student A learner who already holds a first- and/or second-cycle or single-cycle degree and is enrolled in a second- or third-cycle degree programme, such as MSc and PhD students.

Graduate attributes A synonym for *programme outcomes*. In this handbook, we will use the term *programme outcomes*.

Higher education institution (HEI) *"Any institution providing services in the field of higher and/or tertiary education, as defined by national law"* (European Commission: European Education and Culture Executive Agency, 2024, p. 220).

Holistic engineering *"A cross-disciplinary, whole-systems approach to engineering education"* (Grasso & Burkins, 2010, p. 1).

International Engineering Alliance (IEA) *"A global collective of like-minded organisations focused on quality assurance in engineering education and professional competence. The organisation sets benchmark standards for engineering education and helps support engineers to work across borders and support sustainable communities"* (International Engineering Alliance, n.d.).

Inclusive education *"The ways in which pedagogy, curricula and assessment are designed and delivered to engage students in learning that is meaningful, relevant and accessible to all. It embraces a view of the individual and individual difference as the source of diversity that can enrich the lives and learning of others"* (Hockings, 2010, p. 1).

Information literacy skills *"A set of abilities to identify the need for information, find and evaluate it effectively, and use it in an ethical and legal manner to solve engineering problems. It underpins lifelong learning and supports the critical evaluation of automated information sources"* (ACRL, 2006).

Initiative *"Behavior characterized by its self-starting nature, its proactive approach, and by being persistent in overcoming difficulties"* (Frese & Fay, 2001, p. 134).

Interdisciplinarity This involves combining insights, methods, or approaches from two or more disciplines to address complex problems (Keestra & Menken, 2016; Klein, 2018).

Interpersonal communication skills — Adaptive communication ability The *"ability to reflect on one's own and others' perspectives to adjust communication choices for shared meaning"* (Leandro Cruz & Saunders-Smiths, 2019, p. 13).

Interpersonal communication skills — Interconnection/interrelation ability The *"ability to build trust and sustaining constructive relationships over time"* (Leandro Cruz & Saunders-Smiths, 2019, p. 13).

Interpersonal communication skills — Listening skills The *"ability to attend closely to verbal and non-verbal messages to ensure accurate interpretation."* (Leandro Cruz & Saunders-Smiths, 2019, p. 13).

Intervention *"A manipulation implemented by an external agent (i.e., teacher, researcher) that was intended to change students' cognitions, emotions, and/or behaviours"* (Lazowski & Hulleman, 2016, p.606).

Leadership skills The ability to create *"the environmental conditions conducive to good performance: support of shared understanding, innovation, problem-solving, resilience and learning"* (SEBoK, 2024).

Learning beliefs A person's subjective judgements about a relation between learning and his or her values or attributes (Fishbein & Ajzen, 1975).

Learner identity Individuals *"with a learning identity see themselves as learners, seek and engage in life experiences with a learning attitude, and believe in their ability to learn"* (Kolb & Kolb, 2009, p. 5).

Learning Outcomes (LO) *"Statements of what a learner knows, understands and is able to do on completion of a learning process. The achievement of learning outcomes has to be assessed through procedures based on clear and transparent criteria. Learning outcomes are attributed to individual educational components and to programmes as a whole. They are also used in European and national qualifications frameworks to describe the level of the individual qualification"* (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2015, p. 10).

Learning path or **Programme path** *"The way in which learning is organised"* (translated from the legal Dutch term *"studietraject"*, as defined in Deel 1 – Titel 2 – Art. I.3. – 68° of the Codex Hoger Onderwijs, 2014), for instance through structures

which allow for students to encounter, experience, and reflect on their learning within a curriculum or degree programme, with the purpose of supporting students in developing a clearer sense of their emerging professional identity.

Learning strategies *"An individual's way of organizing and using a particular set of skills in order to learn content or accomplish other tasks more effectively and efficiently in school as well as in non-academic settings"* (Schumaker & Deshler, 1992, p.22).

Learning trajectory *"A well-argued progression of intermediate objectives and pedagogical content, directed toward a final goal. Depending on the precise function, context of application, and target group, these trajectories vary in the degree to which implications for various curricular components are operationalized"* (translated from Strijker, 2010, p.10).

Lifelong learning *"[A]ll learning activity undertaken throughout life, with the aim of improving knowledge, skills, and competences within personal, civic, social, and/or employment-related perspective"* (Commission of the European Communities, 2001, p. 33).

Meeting skills A set of teachable professional competencies that enable engineers to prepare for, participate in, lead, and follow up on meetings effectively. These skills extend beyond generic communication abilities, encompassing technical precision, facilitation strategies, structured decision making, documentation standards, and inclusive participation practices tailored to engineering environments (Galster et al., 2024; Changpueng & Pattanapichet, 2024).

Module A self-contained, formally structured, credit-giving educational component of a degree programme, usually covering a specific topic or theme (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2015).

MOOC Massive Open Online Courses *"allow open entry and are delivered online usually with peer or automated support. They often have large enrolment numbers"* (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2015, p. 73).

Ontology The philosophical study of being; it deals with how you view the world and reality, taking your assumptions about the nature of the world and reality into account (Easterby-Smith et al., 2012).

Open Educational Resources (OER) *"Digitised materials offered freely and openly for educators, students and self-learners to use and reuse for teaching, learning and research; it includes learning content, software tools to develop, use and distribute content, and implementation resources such as open licenses; OER also refers to accumulated digital assets that can be adjusted and which provide benefits without restricting the possibilities for others to enjoy them"* (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2015, p. 74).

Oral presentation skills — Presentation skills The ability to give *"a clear, organised and logical speech and answers questions adequately and with elaboration"* (Leandro Cruz & Saunders-Smiths, 2019, p. 13).

Oral presentation skills — Quality of presentation method The ability to develop “*presentation methods and mediums depending on the topic and target group*” (Leandro Cruz & Saunders-Smiths, 2019, p. 13).

Oral presentation skills — Pitching skills The ability to “*convey and persuade audiences within a short 1-3-minute speech*” (Leandro Cruz & Saunders-Smiths, 2019, p. 19).

Peer assessment Different forms of educational activities in which students review and judge each other’s work and/or provide feedback to each other (Adachi et al., 2018; Fleckney et al., 2025; Topping, 1998).

Perseverance “*The quality or state of maintaining a course of action or keeping at a task and finishing it despite the obstacles (such as opposition or discouragement) or the effort involved*” (American Psychological Association, 2018a).

Positivism The idea “*that the social world exists externally, and that its properties should be measured through objective methods*” (Easterby-Smith et al., 2012, p. 22).

Problem-based learning (PBL) “*An instructional (and curricular) learner-centred approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem*” (Savery, 2006, p. 9).

Professional engineering institutions (PEI) Collective term for professional bodies and trade unions for engineers established to advocate for the advancement of the profession and the development of its members (The Welding Institute, n.d.).

Professional identity The way in which students see themselves as engineers-in-the-making, shaped by their motivations, beliefs, competences, and recognition from communities of practice (Chen et al., 2022, 2023).

Programme The degree programme that a student follows, leading to a formal qualification, usually at the bachelor or master level. In some contexts, this term can also refer to a fixed set of courses, subjects, or modules covering a single discipline, while it is a more flexible concept in other contexts. In this handbook, we use programme in the context of degree programmes only.

Programme evaluation Systematic assessment of a programme and its components to determine its quality or value. In this handbook, we use *programme evaluation* in the context of degree programmes only.

Project-based learning (PjBL) “*An inquiry-based instructional method that engages learners in knowledge construction by having them accomplish meaningful projects and develop real-world products*” (Guo et al., 2020, p. 2).

Project management skills On a process level, this refers to the ability to apply processes, methods, knowledge, skills and experience to achieve specific project objectives for change (Association for Project Management, 2024), according to the project acceptance criteria within agreed parameters.

Programme outcomes (POs) The discrete, observable outcomes expected of graduates upon completion of an accredited engineering programme. This term is also used as a synonym for *accreditation standards*.

Quality assurance *"The process or sets of processes adopted nationally and institutionally to ensure the quality of educational programmes and qualifications awarded"* (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2015, p. 74).

Realism The belief that there is a single truth, and that facts exist and can be revealed through experiments (Easterby-Smith et al., 2012).

Representational literacy This addresses how visual-spatial thinking is externalised, communicated, and refined. It refers to proficiency in dynamically creating, interpreting, and managing visual language of engineering such as via technical drawings, schematics, free-body diagrams, and digital models (Johri & Lohani, 2011).

Resilience *"[T]he process and outcome of successfully adapting to difficult or challenging life experiences, especially through mental, emotional, and behavioural flexibility and adjustment to external and internal demands"* (American Psychological Association, 2018b).

Risk analysis and risk management skills The ability to carry out a risk analysis and manage and mitigate identified risks in engineering design and operations (NASA, 2007).

Scholarly teaching Teaching informed by the latest development on the discipline, as well as research about instructional design and how students learn in general or in a specific discipline (Dewar et al., 2018).

Scholarship of teaching and learning (SoTL) *"The systematic study of teaching and learning, using established or validated criteria of scholarship, to understand how teaching (beliefs, behaviours, attitudes, and values) can maximize learning, and/or develop a more accurate understanding of learning, resulting in products that are publicly shared for critique and use by an appropriate community"* (Potter & Kustra, 2011, p. 2).

Second-cycle degree (SCD) The second step in the higher education degree cycle under the standardized EHEA framework. This is typically a master-level programme, lasting 1 or 2 years, requiring 60 or 120 ECTS to complete. Entry requirement is usually a first-cycle degree or equivalent (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2015; European Higher Education Area, 2018).

SEFI Société Européenne pour la Formation des Ingénieurs/European Association for Engineering Education (www.sefi.be).

Self-direction *"[A]n approach where learners are motivated to assume personal responsibility and collaborative control of the cognitive (self-monitoring) and*

contextual (self-management) processes in constructing and confirming meaningful and worthwhile learning outcomes" (Garrison, 1997, p. 18).

Self-reflection "[E]xamination, contemplation, and analysis of one's thoughts, feelings, and actions" (American Psychological Association, 2018c).

Self-regulation Learners who are *"proactive in their efforts to learn because they are aware of their strengths and limitations and because they are guided by personally set goals and task-related strategies [... involving] self-motivation, and behavioural skill [development... It] involves the selective use of specific processes that they will personally adapt to the learning task"* (Zimmerman, 2002, p. 65–66).

Single-cycle degree (SiCD) An integrated programme under the standardized EHEA framework. It combines both the first and second cycle into one 5- to 6-year degree, requiring 300-360 ECTS to complete, and usually leads to the awarding of a master degree. Sometimes referred to as integrated master's degrees. Entry requirement is usually completion of upper secondary education or equivalent (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2015; European Higher Education Area, 2018).

Spatial ability Cognitive foundation and the capacity to generate, retain, and mentally manipulate visual images in two- and three-dimensional space (Buckley et al., 2018; Lohman, 1994).

STEAM Science, Technology, Engineering, Arts, and Mathematics.

STEM Science, Technology, Engineering, and Mathematics.

Subject This term can refer to a topic within a discipline, for instance the subject of mathematics, but may also refer to a self-contained, credit-giving educational unit. In the latter meaning this handbook employs the term *module*.

Sustainable Development Goals (SDGs) A set of 17 goals as a call to action for the 2030 Agenda for Sustainable Development which were adopted in 2015 by all United Nations members, highlighting the connections between the environmental, social, and economic aspects of sustainable development (United Nations, 2015).

Teamwork — Collaborative goal setting Teamwork refers to the coordinated actions of two or more individuals to achieve a common goal (Driskell et al., 2018; Xyrichis & Ream, 2008).

Teamwork — Diverse, intercultural, and inclusive teamwork The ability to *"[u]nderstand cultural differences, recognize their importance or benefit and stimulate cooperative teamwork among people of different cultures"* (Leandro Cruz & Saunders-Smiths, 2019, p. 14). It includes non-homogeneous, cross-cultural understanding and inclusive collaboration and the ability to work in teams with people of different abilities, gender, and backgrounds, and across hierarchical frameworks.

Teamwork — Engagement This term refers to a person who *"shares information and knowledge with team members and shows engagement with teamwork"* (Leandro Cruz & Saunders-Smiths, 2019, p. 14).

Teamwork — Multi-/inter-/transdisciplinary teams The ability to collaborate “*with team members of engineering disciplines and of other disciplines, including clients*” (Leandro Cruz & Saunders-Smiths, 2019, p. 17), beyond STEM and including AHSS.

Technical skills Competencies and skills ranging “*from the foundation and application of science to the applied mathematical and computational skills necessary to develop technical solutions in the sense of innovation and current demands*”(SEFI, 2025, p. 2).

Theoretical framework In the context of Engineering Education Research, a framework which interconnects ideas, concepts, and relationships of interest in the study, and helps to inform the design of the inquiry (Magana, 2021).

Theory of knowledge interest The theory that humans construct knowledge according to three fundamental interests. In this context, *interest* means a fundamental orientation of human thinking by which humans develop means and methods for promoting life. These interests are technical (control and prediction), practical (understanding through interaction), and emancipatory (reflection, autonomy, and transformation). Engineering education overwhelmingly prioritises the technical interest (Denton, 2011; Habermas, 1971, 1973).

Third-cycle degree (TCD) The third step in the higher education degree cycle under the standardized EHEA framework. This is typically a PhD-level programme, lasting 3 or 4 years. Entry requirements are typically either an FCD and/or SCD or equivalent (European Higher Education Area, 2018; European Commission, Directorate-General for Education, Youth, Sport and Culture, 2015).

Transdisciplinary competencies and skills Competencies and skills that “[a]fford an outward facing, broader appreciation and active engagement with traditional and non-traditional sources of knowledge from both academic and non-academic domains. These encompass skills related to ethical decision-making, sustainability and social responsibility”(SEFI, 2025, p. 2).

Transferable competencies and skills Competencies and skills “*that are needed to adapt to various life contexts and that people can potentially transfer to different social, cultural or work settings*” (UNICEF, 2022, p. 3).

UK-SPEC The Standard for Professional Engineering Competence and Commitment for the United Kingdom, that explains the competence and commitment requirements that engineering professionals must meet to qualify for professional titles such as Chartered Engineer (Engineering Council, 2020).

Undergraduate Learner in a first-cycle degree programme.

Visualisation skills The active, applied processes that draw on spatial ability to construct, interpret, and work with mental images in order to understand and solve engineering problems (Raju & Sorby, 2024; Sorby et al., 2013).

VUCA Volatility, Uncertainty, Complexity, and Ambiguity, indicating factors that leaders should navigate in order for their teams to function in turbulent and uncertain environments (Bennis & Nanus, 1985).

Washington Accord (WA) An agreement, started in 1989, among signatory entities responsible for accrediting tertiary-level engineering qualifications from across the globe to mutually recognize each other's accredited engineering degrees to aid global mobility (International Engineering Alliance, n.d.).

Wicked problems Challenges that are dynamic, complex, interconnected and not easily solved (Buchanan, 1992; Mazzucato, 2018).

Written communication and reporting skills *"The ability to develop a logical, accurate, detailed, and organised written product using the appropriate language and style without grammar mistakes and with accurate references"* (Leandro Cruz & Saunders-Smiths, 2019, p.17).

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AI statement

During the preparation of this work the authors did not make use of any AI tools.

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