4TU.Centre for Engineering Education

Adaptive Performance

Conceptualisation and Mechanisms in Engineering Education

Edited by
Yvette Baggen
Antoine van den Beemt
Marieke van der Schaaf
Jan van Tartwijk

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Preface
by the editors

The 4TU Centre for Engineering Education (CEE) Higher Engineering Education research and Innovation (HEErI) book series is dedicated to advancing research and innovation in higher engineering education. This volume, as part of the series, delves into the critical topic of adaptive performance in engineering. It explores how the development of adaptive performance can be stimulated and assessed within both learning and work contexts.

In response to societal changes, higher engineering education is increasingly seeking innovative educational concepts that integrate deep disciplinary knowledge with a broad understanding of other disciplines and systems. Future professionals must be flexible and adaptive, capable of making informed decisions based on complex and often limited information. A common thread in innovative educational approaches such as problem-based learning, challenge-based learning, and transdisciplinary learning is the cultivation of adaptive expertise and the ability to demonstrate this expertise in everyday practice.

However, adaptive performance is seldom explicitly addressed in the literature on these concepts. This gap inspired the editors of this volume to compile a diverse array of practices that illustrate and explain adaptive expertise and performance, highlighting its relevance and providing inspiration for educators and researchers.

This volume presents a collection of studies on adaptive performance, organised into thematic sections that address:

- Part I The conceptual deepening and underlying mechanisms of adaptive performance in the context of workplace-based learning in engineering.
- Part II Methods for stimulating adaptive performance in various contexts.
- Part III Formative assessment of adaptive performance.

We as the editorial team for this volume are deeply grateful to the 4TU.CEE HEErI editorial board for the opportunity to publish this volume. We also extend our heartfelt thanks to the authors for their dedication and effort, which has resulted in a series of chapters that are highly relevant to educators and researchers in the field of engineering education and beyond.

1 | Introduction: **Adaptive performance in engineering in times of uncertainty and change,** conceptual backgrounds

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1 | Introduction: **Adaptive performance in engineering in times of uncertainty and change,** conceptual backgrounds

A. van den Beemt [1], M. van der Schaaf [2], J. van Tartwijk [3], Y. Baggen [4]

ABSTRACT **This chapter provides conceptual backgrounds to the topic of adaptive performance in the context of engineering. It describes how engineers' adaptive performance develops and how this development can be supported in work- and learning contexts.**

Adaptive performance refers to the ability to solve new, complex problems in changing environments and new situations. On the one hand this demands domain related knowledge, skills, and attitudes of engineers.

On the other hand, it is the environment that can facilitate or restrict engineers' possibilities of showing adaptivity in their performance. Especially learning environments should allow for frequent experiences with complex tasks and wicked problems, interdisciplinary experience in different situations, and feedback and reflection on experiences.

This book refers to examples of learning approaches that match with these elements, such as challenge-based learning. This chapter aims to provide a conceptual discussion about adaptive performance in the professional domain of engineering. After an overarching conclusion the successive chapters in the book are laid out.

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In this chapter, we relate adaptive performance to three main topics. First, we address how the concept of adaptive performance can be embedded in the literature on engineering education. In this part, we connect the concept of adaptive performance to creativity and critical thinking as essential parts of adaptive task performance in engineering. Second, we explain how engineers' adaptive performance develops and emerges over time. Third, we briefly touch upon how engineers' adaptive performance can be stimulated in different contexts.

We conclude with an outline of the chapters of this book, including the contexts in engineering (education) they touch upon. The chapters are organised in answering the central research question of the book: What is adaptive performance in engineering and how can adaptive performance development be stimulated and formatively assessed in learning/work contexts?

Conceptualising adaptive performance

Engineers increasingly contribute to solving complex sustainability problems (Lönngren, 2019) as for instance captured in the Global Sustainable Development Goals of the United Nations (UN Desa, 2019). These problems are ill-structured, characterized by uncertainty, unpredictability, and change. Solving such complex problems requires efforts from different stakeholders and experts (Lönngren, 2019). Characteristics of these complex problems are (1) that they can be analysed at multiple levels of abstraction, (2) that they include uncertainty, and (3) that expertise and (transdisciplinary) collaboration are needed to come to feasible solutions.

In the domain of engineering education, the learning tasks of solving such problems are known as challenges (Johnson et al., 2009; Malmqvist et al., 2015). Challenges are perceived as self-directed work scenarios in which students engage (Johnson et al. 2009; Gaskins et al. 2015). Rather than solving the problem itself, the goal of these challenges is to learn to define and address the problem, and to learn what it takes to work towards a solution (Van den Beemt, et al., 2023a). However, the final deliverable can be a tangible solution or a proposal for a solution to the challenge (Membrillo-Hernández & García-García, 2020).

For example, a challenge could address dementia as a growing problem in healthcare. Not only because of human suffering, but also because it increases work pressure for health professionals. One question that can be derived from this challenge is: How are artificial intelligence-based solutions useful to address this problem? A solution then could be to develop a robot that supports professionals. Other questions that need to be answered during the process are: How to develop a robot that suits this context? What interactions should the robot be able to engage in with elderly? And how to make sure that the robot enables healthcare providers to relate to the data the robot gathers?

Challenge-based learning (CBL) is increasingly adopted in higher education institutions to educate students as change agents for sustain-

ability problems (Gallagher & Savage, 2020; Malmqvist et al., 2015). In CBL, students work in interdisciplinary teams on authentic, complex challenges. CBL can be perceived as an educational concept (Van den Beemt et al., 2023a) capturing different educational practices and teaching methods. At the core, CBL is student-centred and has its focus on personal and professional development of students in the process of solving complex challenges (Maya et al., 2017; Membrillo-Hernández & García-García, 2020; Van den Beemt et al., 2023b).

Simply applying standard operating procedures are insufficient for such challenges, because they are characterized by uncertainty (Caratozzolo, et al., 2020). Navigating through this uncertainty is also known as adaptive performance. Adaptive performance refers to an elevated level of performance in unfamiliar situations based on an understanding of why certain actions are useful in certain situations (Chang et al., 2017). In the context of engineering education this approach to adaptive performance is closely related to the T-shaped professional model (Gardner, 2017), which combines in-depth disciplinary expertise with the ability to work with a broad range of people and situations (Gero, 2014). Adaptive performance is shown in the performance of an adaptive expert, which is triggered by a change in task or in the environment which is new for this expert (Pelgrim et al., 2022).

Adaptive experts can be distinguished from routine experts (Hatano & Inagaki, 1986). Both are experts, considering that they meet Ericsson's definition of experts as those who consistently perform better than others on tasks that are representative for the domain of expertise at hand (Ericsson et al., 2018). But where routine experts perform tasks at high levels of efficiency and effectivity in stable, predictable work environments, often working through protocols and established procedures, adaptive experts can successfully manage challenges and tasks that are new to them and that are new in their domain in a creative and flexible way. Adaptive experts have a good dose of resilience, self-regulation and self-insight (Bohle Carbonell et al., 2014; Ward et al., 2019; Pelgrim et al., 2022).

Also, the way in which adaptive experts' knowledge is organised differs from that of routine experts. The knowledge of adaptive experts is more abstract -or more declarative or conceptual- and therefore the link to a specific context is weaker. This makes it easier to use this knowledge to solve a new problem in a changed or new situation. Knowledge is not directly linked to performance, but knowledge guides the perception and interpretation of (new) situations and the subsequent decision-making process about performance (Blömeke et al., 2015). The process of perceiving, interpreting and, subsequently, decision making can be regarded as a form of reflection.

How deep reflection processes make adaptive engineers unique

Reflection is a cognitive and affective (emotional) process of creating meaning and understanding from experiences and content. It is often presented as a cyclical learning process that involves several stages, for example, from analysing specific experiences to the development of new knowledge about that experience, which can lead to alternative future actions.

Reflection can be divided in several levels (Kember et al., 2008; Wallman et al., 2008; Mezirow, 1991; Poldner et al. 2014). The lowest level is non-reflective and relates to awareness or perception of an experience or object. Next is 'content reflection', i.e., reflection in terms of questioning or making interpretations of own behaviour and drawing conclusions. The third level refers to 'process reflection.' This includes the creative consideration of alternatives and leads to a different starting point for future comparable situations. The highest level of reflection, 'premise reflection,' is also called 'critical reflection', because at this level one's own presuppositions and premises are the object of reflection, and 'possibility for transformation' (Mezirow, 1991).

Engineers who perform adaptively have deeper conceptual knowledge and show deeper levels of reflection. That is, they not only understand what central concepts underlying the complex problem are and how they work, but also why that is the case. In addition, they understand the relationships between concepts or parts of knowledge in a larger framework, i.e., how chunks of knowledge and skills can be meaningfully related to each other. This allows them to think more deeply and to associate and extrapolate between solutions of different complex problems and situations. Being able to alternately use the processes of divergent and convergent thinking makes them creative in their problem-solving process. Such experts draw their thinking on and analogous to earlier experienced complex problems (Bohle Carbonell et al., 2014).

The need for creative and critical thinking in adaptive performance

Innovation and creativity are considered important aspects for solving complex challenges (Gallagher & Savage, 2020). These aspects can be operationalised in creative thinking (Sternberg, 2003) and critical thinking (Bailin, 2002). Creativity can be defined as "The interaction among aptitude, process and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context." (Plucker et al., 2004, p. 90). In the context of engineering, creative thinking is an essential element of expertise because adequate task performance often involves finding a new and useful solution to a problem.

Devising creative solutions requires divergent thinking, that is, producing multiple or alternative answers from available information by "making unexpected combinations, recognizing connections among distant associations, transforming information into unexpected forms, and the like." (Cropley, 2006, p. 391). However, it also requires finding the best solution to the problem at hand. This requires logical thinking, validating and accuracy. The deeper a person's knowledge of a particular subject, the more opportunities that person has to come to creative expressions (Simonton, 2003).

So, creative thinking goes hand in hand with knowledge. This involves deep knowledge about certain topics that engineers can use flexibly, for instance to solve new problems or problems outside their own profession or specialism (thinking out of the box). Combined with not being stuck in rigid routines, engineers can produce original and useful solutions. Spiro

et al. (2013) call this combination "cognitive flexibility". This flexibility allows adaptive performers to constantly restructure, reorganise and refine their knowledge for solving complex tasks in context (cf. Feltovich et al., 2006).

Critical thinking contextualises creative ideas, by examining what constellation of resources is needed in particular contexts in response to particular challenges, and what the range of application is for those resources (Bailin 2002). In engineering education, teachers in their role as coach guide students in formulating questions that explore these required resources, for example by clarifying what knowledge students need to develop. Engineering students with adaptive expertise bring critical thinking into new problems by asking many questions in new situations, identifying relevant content, and making connections (Froyd, 2011). They can choose to start from either content emphasis first, or process emphasis first. However, to address today's complex challenges, eventually a balance between content (product) and process needs to be found (Van den Beemt et al., 2023a).

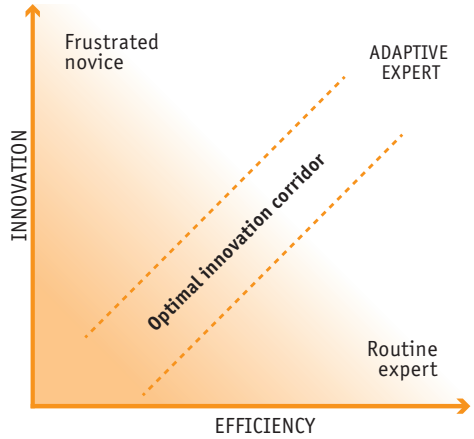
Development of engineers' adaptive performance

To develop engineers' adaptive performance, it is important to give them challenges that are just above the level of their abilities at that moment and that they can conduct with the support of a person who has more expertise, for example from a supervisor. This means that challenges should fit engineers' zone of proximal development to be effective for learning.

This zone of proximal development is also referred to as the 'adaptability corridor' (see Figure 1) (Bransford et al., 2005). Giving a beginner an innovative task that is above this corridor can lead to frustration, while giving tasks to a professional which he or she already masters can lead to higher levels of efficiency or routine, which in the long run may even become less effective if applied thoughtlessly (Choudhry et al., 2005).

The process of developing expertise can be sped up considerably by systematic efforts

FIGURE 1 ADAPTABILITY CORRIDOR (ADAPTED FROM BRANSFORD ET AL., 2005)



to improve task performance. Such a process is referred to as *deliberate performance* (Fadde & Klein, 2010; Van Tartwijk et al., 2023), a concept which was coined by Ericsson and colleagues as *deliberate practice* (Ericsson et al., 2013). This implies that in curricula aimed at the

development of expertise, learners should be able to systematically improve tasks performance. This requires learning environments in which they learn to deal with constrains and use opportunities for optimal task performance. Typically, such learning environments are in realistic contexts that students work and learn in such as internships and learning trajectories in the workplace aimed at professional development.

Training principles that stimulate the development of adaptive performance within such learning environments are known as: frequent practice with feedback and active reflection on experiences and person; developing multidisciplinary experience through practice with different complex cases and in different situations and contexts; tailor-made support by a supervisor (Bohle Carbonell et al., 2014; Kua et al., 2021; Mylopoulos et al., 2018; Wallin et al., 2019; Ward et al., 2018). Two routes in training are known to stimulate cognitive flexibility.

First, to develop expertise by (assignments that stimulate) the use of multiple perspectives, different disciplines, or trying out several paths to solving complex problems. This stimulates openness to and getting acquainted with different perspectives. Second, by learning from mistakes. Unsuccessful attempts to complex problem solving give information that can be used as internal feedback that certain solutions do not work. This can trigger the search for alternatives and looking to the problem differently. In the case of complex tasks, this can lead to new original ideas. Weisberg, (2018) systematically elaborates on this principle for countless creative examples in history.

Stimulating the development of adaptive performance in learning and work contexts

Stimulating the development of engineers' adaptive performance always takes place in interaction, i.e., interaction between the engineer and the (work) environment and interaction with artifacts and others, such as machines and colleagues that are part of that environment.

This implies that the perception or sensemaking process of the environment by professionals is crucial and that it is guided by (a) existing knowledge and views (after all, you see what you think you see) and (b) sensory experience. Sensemaking is the effort to experience and understand events and is often triggered by unexpected circumstances that allow us to view situations consciously and through a new lens, and question and revise earlier interpretations (Ward et al., 2018). This process supports identifying problems and attaching meaning to findings.

Conclusion

This chapter provided conceptual backgrounds to adaptive performance as a way to navigate in uncertain tasks, environments and wicked problems in the domain of engineering.

Adaptive performance is based on being efficient and innovative toward changing tasks and environments. It is explained how adaptive performance demands domain knowledge, deep reflection, creativity, and critical thinking. To develop toward adaptive performance, it is important that the balance

between innovation and efficiency needed for this navigation, fits the level of expertise of the person. This is also known as the adaptability corridor (Bransford et al., 2005).

The foundation for adaptive performance lies in the interaction between the organisational demands in workplace and learning environment and the characteristics, knowledge, skills, and attitudes of the professional. The interplay between the two, i.e., task/context and professional, contribute to engineers' sense-making processes of environmental 'cues,' which is needed to identify problems and direct strategies for solution. Given the interplay between task environment and professional, challenges to develop adaptive performance lie also in institutional change and technological innovation.

Outline

With this book, we aim to contribute to the understanding of how adaptive performance develops, how learning/work environments can be designed to support this, and how the concept can be formatively assessed. The next chapters provide a wide variety of research and state-of-the-art developments in the topic of adaptive performance within engineering in different contexts and countries.

The contributions in this book stem from a shared urgency: the need to train professionals who are not only competent in their field but also agile, reflective, and creative in dealing with new, complex learning/work situations.

The chapters are organised in answering the central research question of the book: What is adaptive performance in engineering and how can adaptive performance development be stimulated and formatively assessed in a learning/work context?

The book is structured in three parts.

Part I regards the conceptual deepening and underlying mechanisms of adaptive performance in the context of workplace-based learning in engineering. This starts with chapter 2 in which Groenier and colleagues discuss three Dutch cases of innovative workplace-based learning environment that support adaptive expertise. In their study supporting working mechanisms, such as collaboration, self-regulation, and dealing with complexity, are identified. They also synthesize important design principles, particularly the interaction with others and working on open-ended tasks.

In three following chapters by Munneke & Ommering (chapter 3), Kaffka & Backhaus (chapter 4), and Gamborg & Jensen (chapter 5), conceptual backgrounds and underlying mechanisms of adaptive performance are deepened from different perspectives. The chapters elaborate on the concept of adaptive performance with cases and examples from contexts in three countries.

In chapter 3 Munneke and Ommering explain the meaning of epistemic agency as a driver for knowledge creation. They show how adaptive performance requires knowledge creation, not just knowledge reproduction and how epistemic agency develops through intentional engagement in context. They illustrate their chapter with

examples from the context of Dutch higher education. Chapter 4 by Kaffka & Backhaus, describes agile methodologies, such as Lean, as a didactic approach to support workplace-based learning through an iterative process, perspective shifts, and metacognitive growth. A case from the German construction sector is included. Chapter 5 by Gamborg & Jensen take an embodied cognition perspective to describe the essence of bodily interaction with the environment as part of adaptive performance. In this Danish study, they illustrate how cognition is inseparable from motor actions and how adaptive performance is based on affordances in contexts. The chapter describes the shift in focus from purely mental processes to embodied knowledge and action in engineering.

Part II mainly concerns how adaptive performance can be stimulated in different contexts.

In Chapter 6, Van Bruggen and colleagues focus on the role of teachers and supervisors. They use the Q-sort methodology to stimulate teachers' reflection and awareness in adaptive performance, by making their challenges and beliefs explicit.

In chapter 7, Kaffka and colleagues describe how engineering students can develop adaptive performance through challenge-based learning (CBL). The authors use a cognitive sensemaking perspective. In their study they provide empirical insights into micro-level processes that explain how CBL support development of adaptive performance among students in higher education.

Part III regards formative assessment of adaptive performance. Chapter 8 by Pennings et al. describes the adaptation of a validated existing questionnaire (D-ADAPT) to measure adaptive performance. They provide a measurement tool to be used in learning/work environments.

In chapter 9, Baggen et al. introduce an innovative formative assessment method based on generative Artificial Intelligence (AI), using realistic scenarios for assessment. They discuss the development process and resulting instrument.

In the final chapter, Den Brok gives a conceptual synthesis and overarching conclusion. He describes overarching lessons learned in terms of directions for designing work/learning environments and he provides suggestions for further research and practice.

This book brings together insights from various international research projects focused on stimulating adaptive performance in workplace-based learning environments in engineering. The insights presented are relevant for instructional designers, educators, policymakers, and researchers involved in vocational education and the shaping of future-oriented learning environments.

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2 | Complex work-based learning environments for adaptive expertise development in engineering education: Lessons from three cases in Dutch higher education

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2 | Complex work-based learning environments for adaptive expertise development in engineering education: Lessons from three cases in Dutch higher education

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ABSTRACT

This chapter describes the working mechanisms of work-based learning (WBL) in adaptive expertise (AE) development. AE in engineering is needed because situations and environments are increasingly uncertain, unpredictable and changing quickly. Higher education institutions are challenged to educate for an uncertain future and WBL environments are especially suited to provide students with opportunities to develop AE.

We describe three initiatives in the Netherlands of innovative WBL environments designed to support AE development. Working mechanisms from these three case studies that are part of the Adapt at Work research project are shared. We highlight the need for careful design of WBL environments to support AE development, especially the interactions with others.

Characteristic for AE development in these cases is that students work on open-ended, ill-defined work-based assignments and/or in challenging workplace conditions. To thrive in these conditions, students need a safe learning environment and constructive and adequate support from educators and stakeholders who acknowledge the students as equal partners in a professional role. Room for students to make mistakes, reflect, and show a proactive attitude creates opportunities to explore and try out new ways of thinking and doing.

Implications of the lessons learned from these cases for designing WBL environments aimed at AE development in higher engineering education are discussed.

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Introduction

Engineering is characterised by complex systems with many interacting, interdependent factors that need to be adapted to continuously changing surroundings and unpredictable events. Engineers have to work in environments with multifaceted problems and the outcome of the problem-solving process is often unknown. An important aspect of successful problem-solving in this context is that engineers have "a willingness to deal with novel and challenging tasks in social interaction situations and to understand others' ideas and perspectives" (Lehtinen et al., 2014, p.212).

To be able to adapt to these novel and challenging tasks, engineers need routines and solid domain knowledge to build on and develop new solutions to current challenges (Chapter 1, this book) and find a balance between acquiring routines and innovating practice (Hatano & Inagaki, 1986). As engineering situations and environments are increasingly uncertain, unpredictable and changing quickly, engineers need (to develop) Adaptive Expertise (AE).

Adaptive expertise is the ability to develop new solutions to professional problems or new methods of problem-solving in changing circumstances (Hatano & Inagaki, 1986; Pelgrim et al., 2022; Bohle Carbonell et al., 2014). Adaptive performance is the visible expression of AE, and this is triggered by a changing task or environment (Pelgrim et al., 2022). This change refers to a change that is new for the professional or that is new for people in general (Pelgrim et al., 2022).

To prepare students for an uncertain future and help them develop AE requires the design of learning environments that rely on authentic, yet ill-defined, tasks that ask for new approaches. It requires a balancing act between innovation and efficiency, i.e., finding the optimal innovation corridor (Chapter 1, this book).

However, there is a lack of empirical studies showing how students can be supported in developing AE through WBL in higher education programmes, aimed at solving authentic, ill-defined or non-routine problems (Kua et al., 2021; Pelgrim et al., 2022). To improve the educational design of WBL for AE development, a deeper understanding is needed of the underlying processes, structures and dynamics, i.e., working mechanisms, that explain how specific educational methods, practices and interventions lead to specific outcomes.

Therefore, in the presenting chapter, we describe how three different learning environments support AE development of future engineers. Each learning environment has its own design characteristics and focuses on a specific group of students who work on engineering problems or bring an engineering perspective on societal problems.

Work-based learning and adaptive expertise development

To thrive in an uncertain future, engineering professionals need AE to be able to navigate successfully in altered situations and changing circumstances (Pelgrim et al., 2022; Kua et al., 2021). The understanding of such dynamic, complex situations is often biased by a reductive tendency to simplify: Feltovich et al. (2001) refer to the tendency to try to preserve misconceptions as knowledge shields. Overcoming these knowledge shields requires deliberate effort, and Ward et al. (2018) present a set of principles for designing learning environments to support AE development.

One of the central principles is not to reduce the complexity of the problem at hand but to preserve the complexity of important concepts and their relationships and help students grasp and deal with these. A study by Veltman et al. (2021) showed that students might cope with the tension of this complexity by avoiding risks and uncertainties and by limiting contact with others, thereby reducing learning potential. Work-based learning (WBL) environments can provide these challenging, ill-defined real-world problems in which the complexities of the problem at hand are preserved.

Such WBL learning environments, in addition to more traditional master-apprentice learning environments and theory-driven (tutorial) lectures, are likely to support the development of AE (Groenier et al., in press). WBL arrangements can vary greatly: from alignment models on the end of the spectrum, in which students switch from one context to another, to hybridization models at the other end, whereby both contexts are merged into one new learning environment (Bouw et al., 2019). Ideally, WBL in higher engineering education is designed based on an intricate interplay between the educational programme and practice requiring not only an effort from the educational institutions but also from the workplace.

Moreover, shifting from traditional engineering education to WBL arrangements for AE development suggests that the role of the educator also needs to shift from a more directing role towards a coaching role (Goldberg & Somerville, 2014; Groenier et al., in press; Veltman et al, 2022).

Currently, many higher education institutions are redesigning their curricula in the face of a changing world and are experimenting with integrative forms of education such as challenge-based education, case-based reasoning, interprofessional assignments and innovative work-learn environments (labs, hubs, apprenticeships). Bachelor and master education can be seen as the kick-off for lifelong learning trajectories, in which professionals have to develop from a novice status towards an expert status and have to adapt to unforeseen developments by learning and innovating. Professional practice is therefore increasingly involved as a partner in the design and implementation of the WBL arrangements, also in the Netherlands.

To explore how such environments and WBL arrangements contribute to AE development, the Adapt at Work project was launched in 2020.

The Adapt at Work project

Adapt at Work (www.adaptatwork.nl/en) was a practice-oriented research project in higher education (funded by NRO, the Netherlands Initiative for Education Research (40.5.19945.601)) on the development of AE in WBL contexts. A Dutch consortium of five research universities and six universities of applied sciences conducted research into WBL environments in bachelor's and master's programmes, aimed at the development of AE of (prospective) professionals.

Adapt at Work aimed to provide insight into effective learning mechanisms and working mechanisms for the development of AE. The Adapt at Work project covered WBL environments in a wide range of professional domains, including (para)medical, social, engineering, teachers and entrepreneurs. The core of the project consisted of comparative and thematic case studies using realist methodology, in which the operation of WBL in the development of AE is described and explained.

Realist research, initiated by Pawson and Tilly (1997), focuses on the context(s) and underlying mechanisms and tries to explain why a complex (educational) intervention works (or does not work). Important questions are what works, for whom, under what circumstances, why, and how? With a realist evaluation, researchers aim to answer these questions by formulating a programme theory, e.g., the set of assumptions why an intervention is thought to have an effect. For this purpose, so-called Context-Mechanism-Outcome-configurations (CMOs) are formulated.

A CMO does not serve (only) to describe a particular causal chain of reasoning but aims to explain how a specific action in a particular context leads to a certain outcome. Therefore, the focus of this type of research is not to find evidence for particular training interventions (does something work), but to offer a deeper understanding of underlying mechanisms (how/why does something work).

THREE ADAPT AT WORK ENGINEERING CASES

In this section, we highlight three initiatives from the Adapt at Work project. In these cases, innovative WBL environments were designed to support AE development in higher engineering education in the Netherlands. In these cases, the projects that students worked on ranged from alignment (Technical Medicine Case) to incorporation (Smart Solutions Semester, Digital Society Hub) and fully hybrid learning environments (Smart Solutions Semester, Digital Society Hub; see Bouw et al., 2019, for a description of the types of learning environments).

In-depth interviews with curriculum designers, educators, workplace supervisors and students were conducted as part of the Adapt at Work project to identify the working mechanisms of AE development in these specific WBL contexts. First, we describe the three cases, second, we discuss the working mechanisms identified in these cases.

Finally, we provide recommendations for the design of WBL environments based on these cases and the literature.

Technical Medicine: translating between engineering and medicine

Technical Physician (TP) is an emerging profession in healthcare. Technical developments follow each other rapidly, and technical knowledge is indispensable to use technology safely, efficiently and effectively (Groenier et al., 2017). In the Technical Medicine programme, students learn to apply the methodology of engineers to the medical domain which involves problem-solving thinking, analysing a clinical question and developing a treatment plan (see Groenier et al. (2017) for a more comprehensive curriculum description). This requires that students learn to position themselves as TPs in collaboration with other healthcare professionals, especially because many are unfamiliar with the TP profession.

Working on challenges at the intersection of patient care and technology and the positioning of TPs as independent healthcare practitioners requires AE. Internships are the prominent WBL environments in the second and third years of the master's programme.

Characteristics of the WBL environment

In the second year of their master's programme, students undertake four 10-week 15 ECTS internships, i.e., clinical placements in hospitals. Students primarily work on open-ended projects that address a specific technical-medical problem, e.g., how to monitor the harmful effects of mechanical ventilation and adjust this for a particular patient, and they practice clinical skills.

Students rotate internships between hospitals and departments within hospitals. Clinical activities, such as ward visits, outpatient clinic procedures, or assistance during surgery, are ideally integrated with the technical-medical project the student is working on and students are expected to progressively perform such activities independently.

Although students are expected to be able to work independently, this does not mean they work 'solo' or individually. On the contrary, students should demonstrate that they are able and willing to work in a collaborative relationship with other professionals.

Interactions with others

In the workplace, students are supervised by a clinical educator, usually a medical specialist. A technical educator from the university safeguards the level of technical innovation and the professional development (PD) educator from the university monitors students' professional development. The technical and clinical educators change per Technical Medicine internship, but students keep the same PD educator for two years.

During the internship year, students return to the university every other Friday for formal, on-site education. Guest lecturers teach about specific topics relevant to the internships, and there are guided peer-to-peer coaching moments with other students and the PD educator. Guided peer-to-peer coaching often has a set structure, where a group of students delves into a problem or question of one of the participants. In these sessions, the PD educators encourage a critically reflective work attitude so that students learn to act proactively.

The Smart Solutions Semester: The adaptive educator as a pivot in the development of adaptive expertise

Saxion University of Applied Sciences launched a new initiative in 2015 in which third- or fourth-year students from different bachelor programmes collaborate in interdisciplinary project teams of 6-8 students on ill-defined societal and professional challenges (25 ECTS in 5 months). Currently, almost 30 educational programmes are participating, from engineering disciplines mixed with social, economic, and health disciplines. In these programmes, the so-called 'Saxion Smart Solutions Semester' became a formal part of the curriculum.

Challenges (tasks) are provided by professional stakeholders or Saxion's professors and are usually open-ended. An educator team pre-formulates the challenges to ensure that these fit students' zones of proximal development and that learning outcomes can be realised within one semester. Whereas solution directions may be included in the description, it is up to students to determine the specific format, type of solution, and approach. Knowledge from different disciplines is needed to develop a good solution. An example of a project is the development of a flying robot for the physical maintenance of wind turbines. The topics are new for the students, and often, they also contain elements that are new to people in general.

Characteristics of the WBL environment

Student groups usually work in the Smart Solutions Semester environment at Saxion, where they can directly contact their educator or other student groups, but they do also have access to a place in the professional organisation, where they can meet their contact person or other professionals, depending on what the group has agreed upon at the start of the project. Educators were trained to specifically guide the collaboration process, independent of the project content. Because of the interdisciplinary nature of the assignments, these educators are not content experts themselves, even though they often do have some relevant content knowledge related to the project.

Interactions with others

Students meet each other on their own initiative and frequency. Furthermore, they meet weekly with a professional stakeholder and - separately - with their educator to discuss progress and their assessment. Depending on personal preferences (Visscher-Voerman & Van Harmelen, 2019), educators differ in how they guide the project teams, varying between supportive or directive behaviour (Assen et al. 2016).

Educators stimulate the exchange of inter-disciplinary knowledge among students as well as experiential knowledge among professionals, and help the project team set common goals, establish common ground and raise critical awareness (Boix-Mansilla, 2016). This regularly includes individual and group reflection on the different contributions of students and stakeholders to the project and on individual and group learning progress.

If groups decide that they lack certain knowledge to tackle the set task, they can consult other members of the Smart Solutions Semester community, educators or professionals.

Digital Society Hub: Adaptive expertise development in information technology

The Digital Society Hub is one of the many 'living labs' at Hanze University of Applied Sciences. Hanze initiated the Digital Society Hub in collaboration with the local government and multiple corporate enterprises, aiming to catalyse 'innovation in and with the help of IT', for example, on the topic of 'interconnectivity'. The province of Groningen is a rather rural area with limited infrastructure and a demographic decline concerning the number of inhabitants.

To match a specific question or challenge (task) from a company in the region to students from the Hanze, the Digital Society Hub has built a website for 'matchmaking' purposes. On this website, the different questions and commissioning companies are described, as well as a description of 'what expertise one is looking for'. This can be a single student coming from a specific discipline (e.g., electrical and electronic engineering, information technology, or law) or a – monodisciplinary or multidisciplinary - group of students. These specifications are derived from the question at hand. Students have to write a motivation letter and officially apply for the position as if it were an official job offer. In the Digital Society Hub case, we focus on the end-level students from the Network Security Engineering-track (NSE; one of three majors) from the Bachelor programme 'IT-training'. These students worked approximately 5 months on their graduation assignment of 30 ECTS, which is centred around the question from the commissioning company.

Characteristics of the WBL environment

The tasks students work on are usually open-ended. An example of a task is the development of a device that can spot ill potato plants while driving over a field of crops and communicating this to the farmer. In these assignments, there needs to be a project-based approach in which the 'solution direction' is undetermined or unfamiliar. Students are required to conduct a 'project-relevant' research, leading to further substantiation of the product (e.g., specification of requirements, performance testing, literature review). Also, the commissioning company is

required to realise certain prerequisites to be able to function as a 'graduation assignment provider', such as having a professional stakeholder who acts as an educator with a certain higher-level educational background and tasks in the organisation.

Students can work on their assignment at the commissioning company, at the Digital Society Hub itself (a specific building on campus), and - frequently - partially remote (i.e., from the student's home). For students to finish their assignment, they have to demonstrate their ability in five learning outcomes; these learning outcomes are based on the nationally established IT-professional profile. The learning outcomes pertain to 1) analysis, 2) design, 3) realisation, 4) problem solution using a research-oriented approach and 5) interacting with others in a goal-oriented manner. Frequently, one finds prototypes, logs and reflections included in a graduation portfolio.

Interactions with others

Students are expected to encounter and collaborate with different professionals. One of the learning outcomes is interacting in a goal-oriented manner, which illustrates that the IT-training values and stimulates effective collaboration with relevant others and suitable communication, as well as the skill to take another person's perspective, which is embedded in the learning outcome 'problem solution using a research-oriented approach'.

Working mechanisms for adaptive expertise development through work-based learning

The working mechanisms we identified in the three cases based on the case studies illustrate how task characteristics, learner characteristics, reflective practice and characteristics of the learning environment were associated with AE development. In most cases, these working mechanisms interact with each other and should be viewed as interrelated factors contributing to AE development. While portraying them below, wherever possible, we include references to external literature that describe similar mechanisms or provide plausible reasoning.

Task characteristics: Challenging projects

An important characteristic of the projects that students work on in each of the three cases is that they are ill-defined, open-ended and require an innovative or interdisciplinary perspective on the task at hand. A project that is ill-defined and open-ended for everyone involved, i.e., student, educator and professional stakeholder, requires a 'thinking outside the box' mindset. This characteristic ensures that all participants are willing to step out of their comfort zone and are expected to collaborate and learn together during the process of working on the project. These challenging projects require risk-taking on behalf of the student and can thus provide opportunities to try out new approaches or refine existing approaches, i.e., develop AE (Groenier et al., 2023.; Mylopoulos et al., 2018).

Learner characteristics: Self-regulation, professional skills and attitude

Student characteristics identified in the three cases that contribute to AE development are proactivity, self-directed learning skills, critical reflection on their knowledge, skills and professional attitude, as well as having high levels of self-efficacy. These skills enable them to successfully adapt to new situations and try out new ways of thinking and working, i.e., develop AE (Technical Medicine, Smart Solutions Semester). In the context of challenging work conditions or projects, students need to be able to think outside the box and continue to adapt because, with each new step in the project, different expertise or approaches are needed (Digital Society Hub). This can lead to surprising events in the project, and for AE to develop, all those involved in the project need to be open to these learning surprises (Smart Solutions Semester; Gulikers & Oonk, 2019).

Reflective practice: Structuring and guiding reflection

Regular reflection on experiences with working on challenging projects, experimenting and making mistakes increases flexibility and a critically reflective work attitude which are important aspects of AE (Groenier et al., in press; Kawamura et al., 2020; Kua et al., 2021). Eva and Regehr (2008) argue that seeking out feedback on performance from others and reflecting on that feedback increases the quality of learning. In this process, the learner takes responsibility to explicitly seek feedback from others to direct their learning and performance; this is a habit of mind that learners can strengthen through practice (Eva & Regehr, 2008). Our cases illustrate how this support of guided reflection can take different forms.

In the Technical Medicine case, there are regular guided peer-to-peer coaching moments with the same professional development educator that stimulate Technical Medicine students' awareness of their own qualities, positioning and professional role. In these moments, students recognise similar struggles and dilemmas, have in-depth discussions about internship experiences and reflect critically on professional development, thereby promoting self-directed learning and reflection on professional development (Groenier et al., 2023; Kawamura et al., 2020; Kua et al., 2021).

From the Smart Solutions Semester case, we learn that equipping educators with the skills to support students' critical reflection is important. In the Smart Solutions Semester case, students are expected to formulate individual learning goals and steer their personal and professional development. Some students struggle with the uncertainty of such ill-defined challenges and expect their educators to structure the work that needs to be done. Educators should stimulate students' reflection on their experiences.

In this context, feedback from teachers or students can be powerful input for the reflection. Students should feel free to express and receive intensive feedback and use it to further enhance and structure their learning strategies. For teachers, it is important to provide feedback in such a way that it helps students to make sense of the situation and make further choices. This requires feedback literacy from both students (Carless & Boud, 2018) and educators (Carless & Winstone, 2023).

Learning environment characteristics: Psychological safety with room for experimenting and making mistakes

Psychological safety seems key to developing AE in all three cases. In psychologically safe environments, students can experience that there is room for experimentation and making mistakes (Smart Solutions Semester, Digital Society Hub). This stimulates the development of a critical stance and problem-solving skills, which are important aspects of AE (Fadde & Klein, 2010). Students should be encouraged to show a proactive attitude (Smart Solutions Semester). This requires a WBL environment in which educators serve as role models, modelling openness to surprising situations or insights (Gulikers & Oonk, 2019) and supporting students in this process (Digital Society Hub, Smart Solutions Semester).

Furthermore, treating students, stakeholders and educators as equal learning partners – while acknowledging differences in seniority, age, and expertise – was considered supportive of the AE development process (Digital Society Hub). When professionals in the workplace act as clients, dictating the outcome of the task or project, they hinder the AE development process (Technical Medicine, Smart Solutions Semester). Rather, activating the social network – being the professional stakeholder, educator and/or student – improves the quality of the solution or product (Digital Society Hub). This requires a certain level of adaptivity from all involved because, in different phases of a project, different expertise is needed and should be actively sought after in one's network. An open, learning attitude of all participants is essential (Visscher-Voerman & Van Harmelen, 2019) and in this way, a constructive and safe collaborative climate is established.

However, some WBL environments are experienced as less safe than others. In the Technical Medicine case, for example, students have to learn to position themselves during their internships in a conservative and hierarchical healthcare environment (Vanstone & Grierson, 2019) with few Technical Medicine practitioners as role models. This makes the WBL environment challenging and students stated that they need self-confidence to position themselves in the workplace (Groenier et al., 2023). The Technical Medicine case illustrates that creating a safe learning environment at the educational institution, away from the workplace, where students are supported in their professional development process by reflecting on their work stimulates students to position themselves in the workplace and thereby develop AE.

A psychologically safe learning environment should not be confused with a highly structured or predictable environment. Both relate to the context of work and what is acceptable practice in that domain. In some professions, such as firefighting, making errors could result in severe consequences. This impacts how much freedom and autonomy a learner may be given but also to what extent there are opportunities to explore and try out new ways of thinking and doing.

Different perspectives

Peers (Technical Medicine), educators (Smart Solutions Semester) or stakeholders who acknowledge the students as equal partners in a professional role (Digital Society Hub) can stimulate AE development in students by introducing different perspectives on a task, for example, in the case of interdisciplinary learning, and encouraging critical reflection on ways of working or thinking. Guiding students to view a task from different perspectives and cross boundaries is an important educational strategy for AE development (Boon et al., 2019; Bouw et al., 2019). The reframing of data and exploring different perspectives that facilitate AE development resonate with the working processes in engineering practices as described by Kaplan and Vinck (2013): 1) reusing pre-existing solutions, in combination with new designs (akin to reframing); 2) mobilizing a broad spectrum of academic disciplines (akin to different perspectives); 3) changing levels of aggregation.

This learning and AE development does not take place in isolation, but rather in a dynamic, social environment. From the Smart Solutions Semester case, where students work in interdisciplinary teams, we learn that students need to develop skills to open up to other perspectives. They usually tend to focus on their own knowledge, and therefore work side by side. In this sense, they do not work interdisciplinary, but multidisciplinary. Learning from each other and moving forward together needs to be explicitly encouraged and supported (e.g., Van Harmelen et al., 2021).

From the Smart Solutions Semester we learned that openness for interdisciplinary learning, this does not come easy. Working in interdisciplinary teams is still rather uncommon for students. Whereas some students may embrace the academic exchange of knowledge and theories, as they see the benefit of it, others have a primarily practical drive and just want to get to work. From their perspective, the time needed for exchanging

disciplinary knowledge feels like a 'waste of time', since it keeps them away from working on the project. Guided reflection, as portrayed above, is likely beneficial in these situations to help students open up to different perspectives (Smart Solutions Semester) and to reframe the challenge, the data gathered, or the approach to be conducted.

Considerations for designing work-based learning environments

In the workplace, professionals navigate in a social environment where people work, collaborate and learn together. WBL environments need to be carefully designed to support AE development, taking into account the social environment, social interactions, and understanding others' perspectives and ideas (see also Billett et al., 2014; Groenier et al., in press; Goldberg & Somerville, 2014). We can derive several educational design considerations by integrating results from our project with findings from the literature to elicit the working mechanisms described above.

Task characteristics

Working on open-ended, authentic work-based assignments, sometimes in challenging workplace conditions, seems to stimulate AE development. Students need to reflect on what needs to be done, which steps to take and to (re)frame the task at hand to come up with adequate solutions. A question that remains is to what extent work-based assignments are challenging enough and truly allow for different ways of solving the problem and different solutions. Perhaps many domains and problems are complicated rather than complex. What is complicated or complex also depends on what the learner perceives as complex or challenging (Pelgrim et al., 2022).

According to the Cynefin framework (Snowden & Boone, 2007), assignments are complicated when a task requires refined judgment and expertise and when there are multiple right solutions, when they are in the realm of "the known unknowns" (p.3). The challenge of complicated problems is the problem-solving process because these types of problems often have a limited or known number of correct solutions (Snowden & Boone, 2007). In contrast, complex domains or problems are inherently uncertain and ambiguous, and factors and relationships in the environments continuously change. These complex problems are challenging because the very actions the problem solver performs change the task or context (Snowden & Boone, 2007). Complex problems cannot be reduced to a 'take-it-apart-and-see-how-it-works approach'.

A clear distinction between complicated and complex problems often cannot be made in advance. Although complex problems challenge learners to think critically, adapt quickly to changing circumstances and come up with innovative solutions, complicated problems help learners build a solid foundation of problem-solving skills and disciplinary knowledge. Balancing routine, complicated and complex problems or tasks in a curriculum is one of the challenges to finding the optimal innovation corridor to stimulate AE development (see also our introduction).

Collaboration and interdisciplinary learning

Working on ill-defined, complicated and complex problems call for more than a single disciplinary perspective, which is reflected in the interaction with others in the cases. Interactions with others stimulate AE development in terms of adapting current ways of working, developing new ideas about practice and developing AE competencies in general (Groenier et al.. in press). Stimulating boundary crossing learning mechanisms (identification, coordination, reflection and transformation, Akkerman and Bakker, 2011) might be an important educational strategy for engineering education in developing AE (Boon et al., 2019; Vereijken et al., 2023; Fortuin, et al., 2024). This boundary crossing can occur between school and work, between different practices, and also between different disciplines.

It is helpful that students work on open-ended challenges that necessitate an integrated interdisciplinary approach. An integrated interdisciplinary approach can be at odds with a programme that prioritises disciplinary learning outcomes, defining the conceptual knowledge that needs to be central in the WBL environment.

In disciplinary programmes with a focus on expert and routine knowledge, students are socialised by the knowledge, skills, routines, or habits in the particular discipline and they identify themselves with a particular job profile. Being rooted firmly in the discipline, they might find it difficult to be open to other perspectives, whereas curiosity and openness to other perspectives are necessary to learn and adapt (Pelgrim et al., 2022; Visscher-Voerman & Van Harmelen, 2023).

Differences in the qualifications of the assignments, required timeframes and assessment frameworks can hinder AE development through interdisciplinary collaboration. For example, in the Digital Society Hub case, certain questions demanded a combination of disciplinary backgrounds but rather sequentially, and not simultaneously, which limited opportunities for students to work together in interdisciplinary teams. To enable AE development through collaboration, educational programmes are recommended to include learning outcomes and ways of assessment aimed at interdisciplinary collaboration and learning, and to leave room for learning surprises, i.e., unexpected insights or shifts in understanding that emerge during the learning process and challenge prior assumptions. Therefore, in line with Veltman et al. (2021), programmes are encouraged to reconsider the learning outcomes and make the development of AE an explicit part of it.

Preparing students for future learning

We recommend to equip students with professional skills, such as communication, skills to work in interdisciplinary teams and reflection, throughout the curriculum to prepare students to further develop AE in WBL environments. They need these skills to effectively contribute to interdisciplinary teamwork (e.g., in the Smart Solutions Semester case) but also to create and maintain a larger network of stakeholders from different disciplines (e.g., in the Digital Society Hub case). Educators and stakeholders from the professional field expressed in our cases the importance of learner traits such as perseverance and proactive behaviour. Pelgrim et al.'s (2022) review of reviews also emphasised that certain

personal characteristics are related to AE, such as cognitive flexibility and embracing complexity. It takes time to develop interdisciplinary skills and these learner traits. It is therefore helpful – if not necessary – to help students prepare by designing a learning line in which students learn to navigate in tasks or environments with increasing complexity. Students are likely to benefit from proper preparation in the first years of their education, e.g., experiencing what it is like to work for an external client, work in a project team, work with different disciplines and frame a problem themselves. Skills deficits are difficult to diminish during a single semester WBL for AE.

The role of educators

The role of educators is challenging because complex WBL contexts can place great demands on educators' guidance skills. Guiding students in project work asks for a fine balance between directive and supportive teaching strategies, whereas many educators feel most comfortable with more traditional, directive teaching behaviour (Assen et al, 2016). When aiming at the development of AE, it becomes more important for educators to create psychological safety, support reflection, provide relevant feedback and encourage students to have an open approach towards the task and others (Pelgrim et al., 2022).

Frequently, the ill-defined task requires a team of students with different disciplinary backgrounds, as was shown in the Digital Society Hub and the Smart Solutions Semester case. The variation between learners in interdisciplinary groups is large because they have different content expertise and identify with the customs and practices in their particular discipline. Educators should help students establish a common ground (e.g., search for commonalities in the different disciplines to handle the task), raise critical awareness towards their own and other disciplines, and integrate perspectives (Boix-Mansilla, 2016). When students from different disciplines do not share the same knowledge paradigm, it becomes more difficult to collaborate and understand each other and collaborate (e.g., Kolmos et al., 2024).

Variation in these interdisciplinary groups further increases when other stakeholder groups, such as professionals or citizens, learn and work together with students (see e.g., Visscher-Voerman et al., 2024). The larger the variety between learners, the more complex it becomes for educators to respond to the individual needs of the learners and to adapt their teaching behaviour, focusing on what individual students need. At the same time, this is important, as Veltman et al. (2022; 2024) show that students with different learning profiles and different competences in dealing with challenging problems and tasks need different teaching strategies in order to succeed. In addition, to utilize boundary crossing learning potential in developing AE, specific educational strategies are needed to foster boundary awareness and boundary work (Veltman et al., 2022).

Because the task is often ill-defined, this also calls for educator flexibility regarding the content. Some contexts or professional domains are more unpredictable than others or require major transitions in ways of working. Guiding students on AE development in the context of ill-defined tasks

requires AE of the educators themselves to focus on what students need in their learning process (Visscher-Voerman & Van Harmelen, 2023).

Implications for research

Within the Adapt at Work project, we focused on researching working mechanisms during WBL for AE. The cases illustrated that working in complex work-based situations calls upon enormous demands on students and educators. This raises questions such as: how to recognise or develop assignments that call for adaptivity, but are within the zone of proximal development, how could educators be prepared for their new teaching roles and what workplace affordances could support AE development at the workplace? Being able to act in complex WBL settings also raises the question of how students could be guided throughout their curriculum towards becoming adaptive experts.

Is it necessary to first acquire a certain amount of basic knowledge and skills before students can work on ill-defined tasks? And how much, what knowledge, and what skills are needed? What are the underlying mechanisms of interdisciplinary learning and collaboration in AE development? These are examples of relevant questions that need to be addressed to deepen our understanding of AE development during WBL in higher education.

To answer these questions, we first and foremost need robust, validated measures of AE and AE development. Currently, most studies about AE or AE development rely on self-report and self-evaluation and the evidence of other methods, such as mixed methods instruments or design scenarios, for measuring AE or AE development is scarce (Hissink et al., 2025).

Furthermore, longitudinal designs are needed to not only adequately evaluate AE development while students are still in their educational programmes, but also to follow up their AE development at the workplace. Also, a deeper understanding of the conceptualisations of AE that educators have, how they perceive students' AE development and the required educator competencies to support this development is needed. Insight into the educators' perspectives aids in supporting educators in their new role and developing educators' professional development programmes aimed at AE development.

Conclusion

The current societal challenges in the world, e.g., environmental sustainability, responsible consumption and future-proof healthcare, call for engineers who can not only successfully adapt to continuous change but also initiate change to improve practice, i.e., who are adaptive experts. AE development does not happen automatically and many higher education institutions are currently experimenting with new types of learning environments to prepare students to adequately take on these challenges and become adaptive experts. Our cases show that WBL environments can be powerful environments to support AE development of engineering students since they lend themselves well to introducing

authentic, ill-defined tasks. Encouraging students to step out of their comfort zone and be open to surprising events helps them to tackle these kinds of tasks. Furthermore, providing appropriate guidance in reflection and helping students reframe the task at hand and their professional role could further enhance the quality of learning from each other. From our cases, we also learned that acknowledging that all partners involved in these WBL environments are learning, and not just the students, contributes to creating a psychologically safe learning climate with room for making mistakes and learning from them.

The design of WBL environments asks for aligning learning outcomes, learning and teaching strategies, and assessment to AE development. A curriculum pathway with increasingly complex tasks helps students acquire and deepen professional skills, such as communication, inter-disciplinary teamwork, and reflection, as well as openness to uncertainty and different perspectives. Educators have a prominent role in creating psychological safety, and gearing the teaching strategies to the needs of the individual learners.

Ethical approval

Overall ethical approval was obtained from the ethical committee of HAN University of Applied Sciences, number 312.12/21.
Informed consent was obtained from all respondents.
All data were pseudonimised.

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3 | Enhancing adaptive performance through developing epistemic agency and research competencies

Photo: Kazuo Ota | Unsplash

3 | Enhancing adaptive performance through developing epistemic agency and research competencies

E.L. Munneke [1], B.W.C. Ommering [2]

ABSTRACT **In today's dynamic and complex work environment, engineers face continuous changes and new challenges. This chapter explores how adaptive performance can be enhanced through the development of epistemic agency and related research competencies. The case studies of Brice, a vocational-level automotive engineer, and Viola, a master-level research engineer, illustrate how adaptive expertise requires integrating and constructing new knowledge tailored to specific challenges. Epistemic agency, defined as the active and conscious engagement in knowledge creation, enables professionals to identify knowledge gaps, decide how to address them, and create actionable knowledge collaboratively.**

The chapter conceptualises epistemic agency through two components: the epistemic aspect, encompassing the acquisition, understanding and creation of diverse knowledge types, and the agency aspect, emphasising proactive, context-sensitive decision-making. These allow engineering professionals to innovate and adapt within their field. Next, this chapter highlights the role of research competencies in fostering epistemic agency and stresses the need for educational approaches that intertwine research activities with professional tasks and practices. Authentic professional tasks, rooted in real-world challenges, are proposed as the foundation for higher education curricula. This pedagogical approach, exemplified by challenge-based learning (CBL), emphasises interdisciplinary collaboration and knowledge creation.

Ultimately, the chapter calls for reimagining engineering education to prioritise epistemic agency and adaptive expertise, ensuring that future professionals can effectively navigate the complexities of modern work environments. These insights are crucial for preparing students like Brice and Viola for lifelong learning and professional adaptability.

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Introduction

Brice is an automotive engineer with a level 4 vocational qualification. He is working at a garage, specialising in Alfa Romeo and repairing classic cars. Consequently, in his daily practice he mainly repairs diesel and gasoline engines. In his vocational training, there was a lot of focus on electric engines but at that time it did not hold his interest. However, due to the current transition from diesel and gasoline cars to electric cars, Brice will have to switch to electric engines soon.

Viola is an engineer with a level 7 master qualification. She is working at a research and consulting firm that helps clients realise broad prosperity. She is currently developing advice for a big city to come to a zero-emission zone in the centre of the city as part of a project team consisting of different kinds of professionals. Her task is to develop a prediction model for the logistic road flows as a part of a framework with guidelines for coming to zero-emission city logistics. Both the subject of the project and working with professionals from very different fields is new to her.

As professionals in the engineering domain, Brice and Viola both face changes in their daily work due to significant shifts in their work environment (transition to electric driving) or new societal issues (sustainability and CO_2 reduction). To remain well-functioning professionals, Brice and Viola should be able to adjust to new uncertain circumstances, changing complexity of job tasks and work methods. Despite the difference in qualification level of their education, they are both expected to show flexibility in the workplace, which is seen as a critical ingredient for success (Van der Heijden, 2002). This flexibility is the main characteristic of adaptive expertise and the corresponding concept of adaptive performance. At its core, engineers like Brice and Viola can successfully meet uncertain, complex and dynamic challenges in their work – new for the engineering domain or themselves – in a creative and flexible way (Bohle Carbonell et al., 2014; Pelgrim et al., 2022). In other words, engineering professionals like Brice and Viola nowadays are expected to perform professional tasks optimally even in changing contexts, to contribute to societal issues and to pursue life-long learning.

Several reviews into what constitutes adaptive expertise and how to develop it, emphasise the importance of cognitive flexibility (Feltovich et al., 1997) and corresponding solid domain knowledge (Bohle Carbonell et al., 2014; Pelgrim et al., 2022). Therefore, as also indicated in the introductory chapter of this book, engineers who act adaptively can come up with creative solutions to new problems because they have access to rich, conceptual knowledge. The more complex and deeper

this knowledge is, the easier it is for a professional to think creatively and critically, enabling them to develop original, well-reasoned, and useful solutions to new problems in the work context (Feltovich et al., 1997).

However, as the scenarios of Brice and Viola show, what could be seen as the solid domain knowledge of an engineer is subject to change as well, due to the inherently dynamic and context-dependent character of domain knowledge. For Brice, this means being able to further extend his solid domain knowledge in diesel and gasoline engines with knowledge about repairing electric engines. For Viola, this means she should be able to integrate knowledge of other professionals into her own domain knowledge to some extent as well. This indicates that to be an adaptive expert, engineering professionals need to continuously determine which knowledge is needed to deliver good work and should be able to create that knowledge in collaboration with other professionals.

So, adaptive experts can balance the efficient use of their previously acquired knowledge with the creation of new knowledge in response to novelty and complexity (Kaffka et al., 2024; Mylopoulos et al., 2018). Knowledge creation therefore seems to be an essential part of fostering solid domain knowledge and ensuring that engineering professionals remain effective and efficient in dealing with the complexity of today's society and challenges in their daily work.

As Markauskaite and Goodyear (2017, p.1) put it: "Working on real-world problems usually requires the combination of different kinds of specialised and context-dependent knowledge, as well as different ways of knowing. People who are flexible and adept with respect to different ways of knowing about the world can be said to possess epistemic fluency."

In this chapter we zoom in on this aspect of epistemic fluency in adaptive expertise and performance. Building on the work of Damşa et al. (2010) and Heikkilä et al. (2023) we refer to this as *epistemic agency*.

Conceptualising epistemic agency

Epistemic agency refers to the way in which professionals actively and consciously engage in knowledge creation in their daily practice (Damşa et al., 2010; Heikkilä et al., 2023). Based on a systematic conceptual analysis of the literature, we propose that a professional with epistemic agency should be able *to recognise and acknowledge* where adequate (actionable) knowledge is lacking in a specific professional context, *make substantiated decisions on how to deal with the missing knowledge* with *a thoroughness that is appropriate* to the given context, and make the results *useful* within and for specific professional situations *in collaboration with stakeholders* (Munneke, 2024; Munneke et al., 2023).

To further conceptualise epistemic agency, we will first discuss the meaning of the *epistemic* component and what we mean by knowledge in the context of professional work. We then elaborate on the meaning of the *agency* component in the context of new, uncertain circumstances and the changing complexity of work.

The term *epistemic* in epistemic agency refers to the stance of professionals towards *knowledge* and includes everything related to acquiring, understanding, justifying and creating knowledge. Following research on professional expertise, we use the term 'knowledge' in its broadest sense. This includes all contributions to thinking, interacting and performing such as: codified, explicit knowledge; know-how; personal beliefs and understanding; episodic memories; self-knowledge and tacit knowledge (Eraut, 2010). There are many ways these types of knowledge are interpreted by researchers.

However, despite the wide diversity in classifications of knowledge, we can broadly distinguish three different types of knowledge professionals can acquire and use in their work: 1) explicit, formal, explanatory, declarative knowledge (know-that, know-why) such as concepts, models and theories; 2) implicit, informal, procedural, experiential knowledge (know-how) such as skills and dispositions to act in a particular way; and 3) regulatory knowledge that supports ongoing learning and development (Bereiter, 2002; Eraut, 1985; Markauskaite & Goodyear, 2017; Tynjälä, 2008).

Markauskaite and Goodyear refer to the complex constellation of these types of knowledge that professionals need to ultimately deliver quality work, as *actionable knowledge*. They stress that creating actionable knowledge involves much more than developing formal, declarative knowledge, because it requires "a combination of intelligent problem solving, engagement with the material and social environment, and perceptual-sensorimotor skills" (p.90).

In conclusion, the epistemic element in epistemic agency is thus a comprehensive concept and involves the integration of different types of knowledge. This holistic approach ensures that professionals are not only well versed in theoretical concepts (formal, declarative knowledge), but also adept at acquiring and applying existing knowledge as well as creating new knowledge in, with and for practical situations (Schön, 2002). This ultimately leads to continuous professional growth, high-quality work and the innovation needed in that work.

While knowledge construction often occurs as professionals react to specific changes, uncertainties, or problems, *agency* denotes their pro-active involvement in shaping how they respond (Biesta & Tedder, 2007; Kusters et al., 2024). In essence, epistemic agents are not passive recipients of information; they critically assess and contribute to the knowledge they encounter. The definition of epistemic agency we gave earlier in this chapter suggests that this response could take place, for example, at the level of deciding *how* to acquire new knowledge (Greve et al., 2018).

It refers to the ability to make conscious, substantiated decisions about what is appropriate given the context in which professionals are acting, and recognizing that there may be multiple approaches. This is in line with broader perspectives on agency, which imply that professionals are able to consider different ways of constructing knowledge and make deliberate choices based on what is needed for the given context (Eteläpelto et al., 2013; Lutz et al., 2019).

In doing so it is important that they are aware of different types of knowledge and learn to deal flexible with abstract, contextual and situated ways of knowing to derive actionable knowledge (Guile, 2014; Heusdens et al., 2015). This involves a unique interpretation of what is considered actionable knowledge, while relating this to the shared understanding of the professional community of which a professional is part. In other words, professionals relate to a particular system with its corresponding 'epistemic frame' – i.e., "a system of ideas or ways of understanding that allows us to establish knowledge [...] manners of justifying, explaining, solving problems, conducting enquiries, and designing and validating various kinds of products and outcomes (Perkins, 2006, p.42)".

Finally, it requires the ability to look beyond your own theories and practices, to delve into expertise beyond one's own, to engage in multi- or transdisciplinary collaboration, and learn from other fields (Ninan et al., 2022).

Returning to the cases, how does epistemic agency help Brice and Viola to deal adaptively with the challenges of their daily practice? For Brice, epistemic agency supports the acquisition of new actionable knowledge, as the combination of explicit, implicit and regulatory knowledge enables him to effectively repair and maintain electric engines. Brice will need to engage with the latest information and technologies related to electric engines. In his case, this means revisiting the concepts he learned during his vocational training and updating his knowledge base to include recent advances in electric vehicle technology. Brice's ability to understand and justify the new knowledge is crucial. He needs to understand how electric engines differ from diesel and gasoline engines, not only in terms of mechanics, but also in terms of their environmental impact and efficiency.

This deeper understanding will enable him to justify the transition to electric engines both to himself and to his clients. When he becomes more familiar with electric engines, he can start to innovate and create new solutions tailored to the specific needs of his garage and clients. This could involve developing new repair techniques or customising electric engines for classic cars, combining his expertise in both areas.

In the case of Viola epistemic agency can also assist the acquisition and creation of new actionable knowledge necessary to develop a predictive model for zero-emission city logistics in collaboration with professionals from other domains. In her case, acquiring new knowledge means Viola must actively seek out new knowledge related to zero-emission zones and logistics road flows. This involves researching current best practices, understanding the latest technologies, and learning from case studies of other cities that have implemented similar initiatives. She also needs to be able to delve into the knowledge of other professional domains of the professionals she works with (e.g. urban planning, environmental science).

To some extent, she will have to learn to speak the language of fields that were previously foreign to her. Viola needs to deeply understand the principles behind zero-emission logistics and be able to justify her

predictions and recommendations. This involves not only grasping the technical aspects of her prediction model but also understanding the broader environmental and social impacts of zero-emission zones. In her own specific context, she will likely encounter unique challenges and opportunities. Epistemic agency enables her to innovate and create new solutions tailored to this context. This could involve developing new algorithms or integrating diverse data sources to improve the accuracy of her model.

While both Brice and Viola use epistemic agency to adapt and innovate in their fields, there are notable differences between their cases. Brice's work is more focused on a specific technical domain, while Viola's work spans multiple domains. Brice integrates new technical knowledge into his existing skill set, whereas Viola must synthesise knowledge for various fields to create a comprehensive solution in interdisciplinary collaboration with other professionals. By understanding these differences, we can see how epistemic agency is applied uniquely in each context on different levels, enabling both Brice and Viola to respond adaptively to the specific challenges in their context.

Fostering epistemic agency in engineering education through developing research competencies

What are the implications of this conceptualization for teaching and learning epistemic agency in higher education? To start with, Markauskaite & Goodyear (2017, p.553) state: "we claim that well-designed tasks for professional learning are simultaneously professional (actionable, situated), conceptual and epistemic. Such tasks involve the weaving of epistemic games that are played in professions and a dynamic – embodied and embedded – assembling of actionable concepts. These tasks stimulate discourse that integrates generic (formal) and situated (functional) kinds of knowledge and formal and functional ways of knowing. They involve knowledge that is both coherent and contingent, structured and experiential and explicit and tacit".

Firstly, this statement makes it clear that authentic professional tasks are the starting point when designing higher education to develop epistemic agency. In doing so, Markauskaite and Goodyear indicate that a variety of more or less (ill)structured and (in)stable tasks are needed throughout the curriculum that enable meaning-making and action. This is consistent with an important pedagogical principle from the 4C/ID model: increasing complexity of authentic professional tasks (Van Merriënboer, 1997; Van Merriënboer & Kirschner, 2013).

In an increasing number of professional practices, the complexity of the issues that professionals are facing is growing. This means that these issues for which adaptive performance is needed should also be incorporated into the curriculum, and students must gain sufficient experience with these complex problems in addition to more routine professional situations. Therefore, students should not only be challenged to grow into a profession and gain more expertise in it, but also to contribute to the issues and challenges in that profession, which are increasingly multidisciplinary in nature.

Secondly, the statement of Markauskaite and Goodyear focuses on the importance of 'playing epistemic games' as an educational approach. This approach is rooted in the work of Shaffer (2006) on how to master an epistemic frame of a specific profession. While research is a crucial component of an epistemic game, it often becomes the dominant element in higher education (Greve et al., 2018) Although developing students' research competencies is essential for creating knowledge and fostering epistemic agency, it is equally important to maintain a strong connection to professional practice. In other words, the focus must not solely be on research competencies for the sake of conducting research, but on producing actionable knowledge for professional situations and problems.

So, research competencies can be seen as supportive and valuable for developing epistemic agency (e.g. Heikkilä et al., 2023; Markauskaite and Goodyear, 2017). Despite the necessity for professionals in practice to find answers in situations of not-knowing through more iterative and pragmatic methods, contemporary higher education often places students in the role of researchers. This frequently results in a unilateral approach with a strong focus on technical research skills, expecting students to conduct research systematically and methodically following the research cycle to acquire knowledge (Greve et al., 2018). However, when it comes to educating future professionals for certain domains this approach is not always the suitable epistemic game for developing actionable knowledge in professional contexts.

Instead, higher education should aim to cultivate professionals that develop epistemic agency and are able to deploy research competencies to truly benefit the profession. Professionals should know how to act in complex situations and help to evolve the professional field, which goes beyond just teaching technical research skills and providing students with opportunities to take on a researcher role. Still in many educational contexts the development of research competencies often occurs disconnected from future professional tasks in practice.

Instead of pursuing the 'quality of knowledge creation' as professional researchers do, the focus should be on the 'quality of work' (Ruijters & Simons, 2020). The standards of what constitutes good work should therefore be the determining factor, which in turn redefines the concept of research competencies.

Thus, research competencies are supportive in developing epistemic agency and should be closely linked to 'good work' in the future daily practice of professionals. This implies that a broader didactic approach to developing research competencies to foster epistemic agency is needed, beyond merely conducting research. Instead, it should focus on producing professionals capable of handling the dynamics and complexity of professional practice.

In conceptualising epistemic agency, we referred to our definition arisen from a systematic conceptual analysis of the literature. This same conceptual analysis also helped to identify five dimensions of research competencies, each with its own constellation of knowledge, skills, and attitudinal aspects (Table 1, p.43).

TABLE 1 DIMENSIONS OF RESEARCH COMPETENCE

DIMENSION	DESCRIPTION/DEFINITION	EXAMPLES OF KNOWLEDGE, SKILLS AND ATTITUDES
Conceptual *What is it about?*	Epistemic agency cannot be expressed if there is no knowledge of the subject or situation. The richer the cognitive, conceptual schema of a topic/domain, the better one can assess what they do and do not know, and the easier it is to arrive at new knowledge (Feltovich et al., 1997).	- Conceptualising - Concretizing - Information literacy
Epistemological *What are our values and norms when it comes to knowledge?*	Every domain has its own peculiarities when it comes to the value and assessment of knowledge. Professionals are initiated into that tradition with its own focus, views, norms and values. This makes this dimension normative at its core.	- Scientific and epistemological beliefs - Common research methods or practices (e.g. action research or design research)
Procedural - technical *What are our ways of working?*	To answer a knowledge question systematically and methodically with appropriate rigor, one needs to be able to go through a research cycle and master the corresponding technical research skills. Which these are, is closely related to the epistemic dimension.	- Concepts of reliability, validity - Methods of data gathering and - analysis - Operationalizing variables
Affective-motivational *What does it evoke emotionally?*	The words 'research' or 'not-knowing' evokes emotional responses such as uncertainty, fear and pleasure in many people, motivating them more or less to want to 'research'. Being able to deal with these emotions in a good way contributes to epistemic agency. How, for example, could uncertainty be productive?	- Dealing with uncertainty - Perseverance in the face of frustration and complexity - Awareness of added value of research for own professional practice
Social-communicative *How to create relevant and usable knowledge collaboratively?*	How to collaborate well with others in answering questions so that the answer is useful to more people than? That includes being able to communicate clearly about answers to a knowledge - question, and being able to convince others about the validity of those answers.	- Argumentation skills - Writing skills - Collaboration skills - Presentation skills

This table illustrates the versatility of developing research competencies and, consequently, epistemic agency. Instead of the current predominantly one-sided emphasis on the procedural-technical dimension, attention must also be given to the other dimensions. It is important to keep considering that students are being prepared for specific professional practices. Therefore, starting with 'not knowing' or knowledge gaps that occur in concrete tasks within that particular practice is key. This highlights the importance of focusing on authentic professional tasks (Van Merriënboer & Kirschner, 2013).

Discussion

Higher education seems to be increasingly embracing the idea of focusing on authentic professional tasks. This is reflected, among other things, in the emergence of various forms of education in which there is close collaboration with partners from practice and society. In these educational approaches, epistemic agency becomes a shared endeavor, with subsequent questions about what is considered as valuable knowledge within a group (Damşa et al., 2010). This poses new challenges with implications for educational practice. Below, some of these challenges will be discussed through the lens of the widely adopted educational concept of challenge-based learning (CBL) in higher education.

CBL is a promising approach that emphasises the importance of focusing on authentic professional tasks. In CBL, students tackle real-world and complex challenges within an interdisciplinary team (Gallagher & Savage, 2020; Malmqvist et al., 2015; Van den Beemt et al., 2022).

First, CBL provides students with important learning opportunities in terms of epistemic agency, as they can contribute to authentic issues and challenges in the profession through knowledge creation. In addition, however, it is equally important to focus on their professional growth and expertise when shaping CBL. Especially since the educational concept of CBL, at its core, focuses on both personal and professional development of students (Maya et al., 2017; Membrillo-Hernández & García-García, 2020). Therefore, CBL, which involves students collaborating on mission-driven projects around complex tasks, requires careful design and alignment with their stage of professional development and current level of professional knowledge.

Viola's story illustrates that she is not only collaborating with professionals from various fields for the first time, but she is also deepening her expertise in her own profession. She is acquiring more complex professional knowledge through new professional tasks such as developing prediction models and constructing guidelines for zero emission city logistics. This is where Viola's epistemic agency and underlying research competencies are needed as they allow her to actively engage in knowledge creation both at the substantive and collaborative level. Engineering education could have prepared Viola for these kinds of situations by taking professional practice and the subsequent tasks and products as a starting point, and by centering education around these specific professional tasks that require particular competencies.

By doing so, it is then important to give explicit attention to the major 'knowledge questions' that arise in those tasks and the methodologies in a profession itself to answer those questions (Greve et al., 2018). Specifically, in educational approaches such as CBL, this means it is important to closely integrate research activities with professional tasks, rather than asking students to first conduct research to develop knowledge and then apply that knowledge. With this many programmes in higher education thus place a one-sided emphasis on the thoroughness of research and maintaining a critical distance from practice, rather than focusing on solving practical problems and students' professional actions *in* and *with* their own professional practices.

Consequently, this often leads to the complaint that students' knowledge creation through research has little value or relevance to the original problem in practice to be solved (Greve et al., 2019). Therefore, the knowledge created should also be connected to daily practice to prevent that interdisciplinarity in working on professional challenges become disconnected from growing into that profession and gaining expertise.

Second, even within CBL the challenge remains how to collectively create knowledge in a meaningful way. In higher engineering education, as well as in other domains, there is a strong focus on knowledge sharing and construction, what (Bereiter & Scardamalia, 2014) refer to as the 'belief mode'. In this mode, students mainly engage in learning activities focusing on evaluating, questioning, accepting or rejecting knowledge claims and primarily concerned with truth or falsity of ideas and beliefs. Students are stimulated to assess known knowledge or to create knowledge that is deemed necessary to achieve for educational purposes. In contrast, to what Bereiter and Scardamalia describe as a design mode which involves creating and improving ideas and solutions.

However, guiding them towards creating *new* knowledge and fostering innovation remains a challenge (Van Aalst, 2009). Here, CBL appears promising, but it still originates from the educational objectives. Initiatives are therefore evolving, reflected in the emergence of so-called hybrid learning environments like living labs (Zitter & Hoeve, 2012).

In these living labs, providing education to students is not the sole purpose. Instead, societal issues are at its core and students are – together with teachers, researchers and practice partners – working on knowledge creation. These hybrid learning environments, where education, practice, and research converge towards a higher societal goal, are difficult to causally design or shape in advance based on pedagogical-didactic principles (Carvalho & Goodyear, 2018).

More research is needed in these contexts to shed light on, for instance, 1) the development of both individual and shared epistemic agency, 2) ways to achieve this in collaborations between education, research and practice and 3) capabilities of higher education teachers in their new roles, for instance their ability to ask the right epistemic questions and stimulate knowledge creation of students.

Conclusion

In this chapter, we have discussed the importance of developing epistemic agency and related research competencies to enhance the adaptive performance of (future) engineering professionals. We emphasised the importance of knowledge creation in order to be able to foster sufficient domain knowledge and subsequent flexibility in the workplace – both of which are considered imperative for adaptive performance.

In conceptualising epistemic agency, we highlighted the importance of an agentic stance in creating (actionable) knowledge. Research competencies support the fostering of epistemic agency but currently are addressed in higher education with a focus on procedural-technical aspects and the epistemic game of research, rather than the production of knowledge for knowledgeable action in professional contexts.

We stress the importance of embracing versatility in developing research competencies closely connected to professional practice students are educated for – in other words, the right epistemic game should be pursued. Furthermore, new initiatives in which education is strongly connected to both research and practice bring about their own set of challenges.

Circling back to Brice and Viola, this means that Brice should be able to identify where he lacks actionable knowledge in the context of electric engines, striving for creative solutions for this new context by expanding his actionable knowledge. For Viola, this means that she should be able to determine what knowledge she needs to act professionally in a multidisciplinary team.

The actions of both Brice and Viola accentuate the importance of epistemic agency and underlying research competencies to perform adaptively, which is necessary on all qualification levels. In designing engineering higher education, it is therefore essential to provide students like Brice and Viola with authentic professional tasks that vary in structure, stability and predictability, and to intertwine knowledge creation with these professional tasks, rather than teaching students to do research 'separately'.

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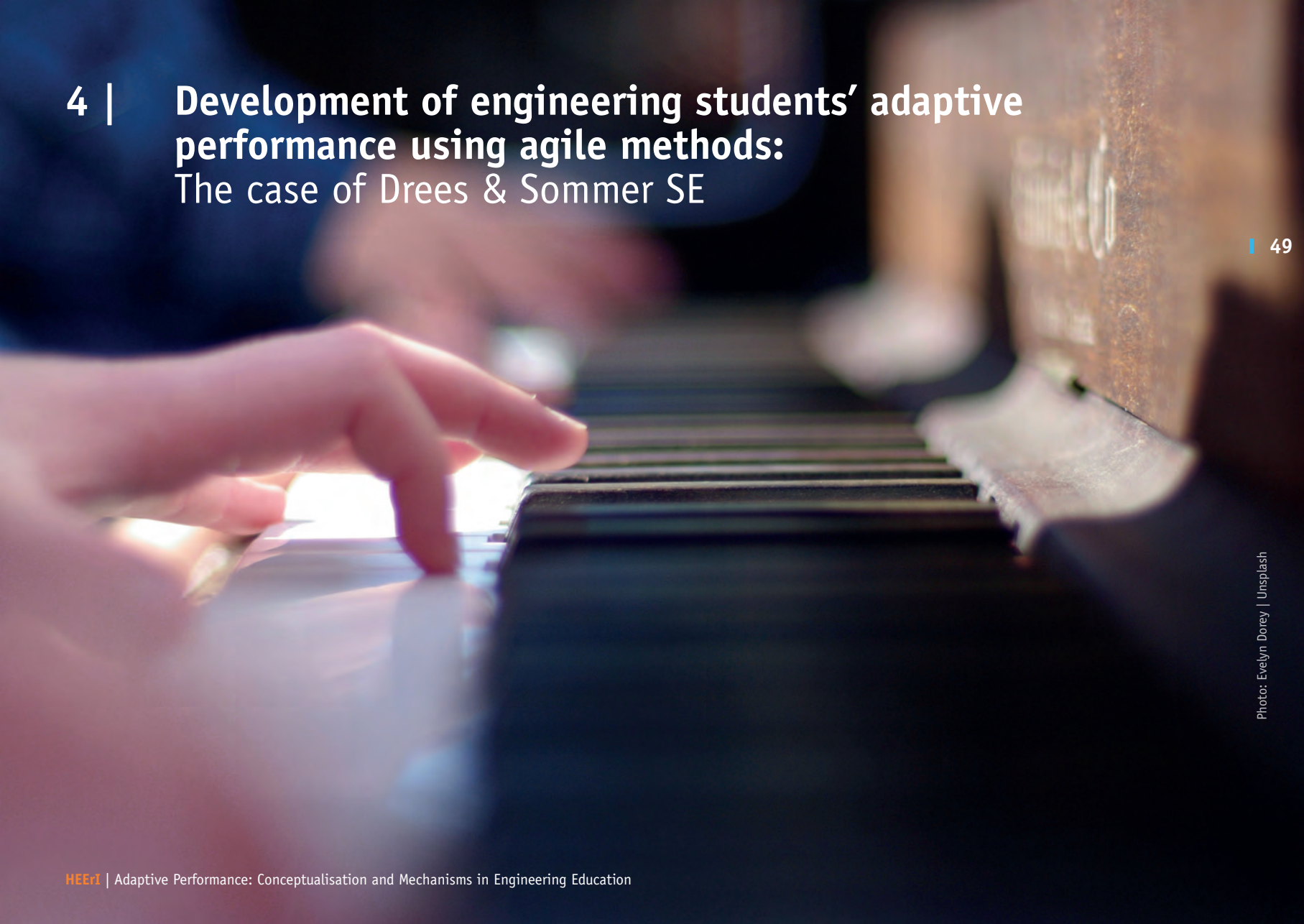
4 | Development of engineering students' adaptive performance using agile methods: The case of Drees & Sommer SE



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4 | Development of engineering students' adaptive performance using agile methods: The case of Drees & Sommer SE

G.A. Kaffka [1], J.O. Backhaus [2]

ABSTRACT **Agile methods contribute to flexible, iterative project management in large building construction projects. In this chapter, we examine the role of agile methods in workplace learning in developing engineering students' adaptive performance. To do so, we focus on studying the micro-level, cognitive processes by which agile methods enable engineering students' adaptive performance development.**

Analysis of an internship programme using agile methods – by means of lean project management - at a large German construction firm shows that agile methods function to develop adaptive performance by means of two mechanisms. One, such methods train students' ability for perspective-taking. Second, they develop students' metacognitive skills. Both are relevant for adaptive performance.

We discuss our findings and address practical implications as well as some limitations of using agile methods in higher education.

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Introduction

Adaptivity enables professionals to tackle non-routine, complex problems in the workplace (Inagaki & Miyake, 2007). Their adaptive performance reflects the ability to adjust cognitive, emotional, motivational, and behavioural responses to shifting task demands or unfamiliar situations (Baard et al., 2014). This capacity manifests in their advanced problem-solving, social, and intercultural skills (Oprins et al., 2018; Pelgrim et al., 2022).

Adaptive performance is highly valued by employers (Hawse & Wood, 2018). Given that adaptive skills rank among the most important qualities sought in graduates (Arce et al., 2022; Nandini, Gustomo, & Sushandoyo, 2022), fostering adaptive performance in higher education has become increasingly important (Kua et al., 2021). This is also the case in the field of engineering education (Hicks et al., 2014).

A study among 71 agile teams showed that agile contributes to team adaptive performance (Steegh, Van de Voorde, Paauwe & Peeters, 2025). Agile methods relate to communication, stakeholder involvement, and adaptivity of professionals (Owen et al., 2006; Ribeiro & Fernandes, 2010). Arce et al. (2022) showed an improvement in engineering students' grades, their complex problem-solving skills, and their own satisfaction with the learning process after learning the use of agile methods. As complex problem-solving skills are characteristic of adaptivity in professionals, these findings indicate that agile methods benefit the development of students' skills relevant for adaptive performance. Similarly, Longmuß & Höhne (2017) found positive results of using agile methods in the workplace learning of students.

Meanwhile, we know little about the micro-level mechanisms by which agile methods used during workplace learning facilitate the development of adaptive performance among students. The objective of this chapter is the identification of mechanisms by which agile methods enable engineering students' adaptive performance development. In this chapter, we seek to answer the following research question: *How does the use of agile methods during workplace learning contribute to the development of adaptive performance among engineering students?* To do so, we examine an internship programme at a large German construction consultancy company which trains students in agile project management (APM).

First, this chapter introduces relevant theory on adaptive performance, its development, and assessment in higher education. Then we describe the concept of agile and how agile methods are used in the workplace. Next, we present the Context, Intervention, Mechanism, and Outcome (CIMO) framework. This framework is used for the analysis of students' use of agile methods in the workplace and how this contributes to the

development of students' adaptive performance. The analysis shows that there are two mechanisms by which agile methods contribute to developing engineering students' adaptive performance. For one, agile methods provide students with exercise in perspective-taking. Second, agile methods train important metacognitive skills. We then discuss theoretical and practical implications of our findings, address limitations of using agile methods in higher education, and make suggestions for future research on this topic. The chapter ends with a short conclusion.

Adaptive performance

Adaptivity enables professionals to handle stress, have superior social skills, and innovative, creative problem-solving skills (Pulakos et al., 2000; Fisher, 2001; Oprins et al., 2018). Adaptive employees are highly sought-after in the contemporary economy (Baard et al., 2014). Small, Shacklock and Marchant (2018) explicitly mentioned the trait of adaptability in their definition of higher education graduates' employability. Adaptive performance of professionals stems from their conceptual knowledge, which goes beyond declarative knowledge (knowing 'what') or procedural knowledge (knowing 'how to').

Declarative and procedural knowledge enable routine expert performance and is based on years of practice in domain-relevant tasks. Conceptual knowledge allows professionals to know 'why' and when to transfer existing knowledge and skills to achieve their task under conditions of uncertainty or novelty (Pelgrim et al., 2022).

Scholars have argued that it is important to develop conceptual knowledge among engineering students - alongside their declarative and procedural knowledge - to build students' adaptive performance (Hicks, Bumbaco, & Douglas, 2014).

Developing adaptive performance in higher education

Education aimed at developing students' conceptual knowledge, i.e. adaptive performance, should emphasise understanding rather than performance, by providing ample opportunity to make inquiries or asking questions, to struggle, risk-taking and failure – all of which in a safe learning environment (Kua et al., 2021). Such education provides opportunities for meaningful variation around conceptual or procedural knowledge (Bransford & Schwarz, 1999; Myopolous et al., 2018).

Generally, students can train adaptive performance with active learning activities that help to develop their learning orientation (Bransford & Schwarz, 1999). Curriculum design which stimulates the development of adaptive performance in higher education includes variability of practice, interdisciplinarity, open learning tasks, use of simulation and cases, and self-directed task selection (Bohle Carbonell & Dailey-Hebert, 2014; Bohle Carbonell & Van Merriënboer, 2020; Van der Schaaf, Schuurmans, Van Tartwijk, 2020).

Teachers can build adaptive performance among students with case-based learning (Ward et al., 2020), by encouraging students to use questions, and by students' engagement in feedback (Charbonnier-Voirin & Roussel,

2012). An orientation towards such feedback-seeking activities is also reflected in the agile method.

Agile methods

The use of agile methods in higher education has increased, notably also in engineering sciences (Neumann & Baumann, 2021). Agile methods are plan-based rather than planning-driven (Malik et al., 2021) because they emphasise iterative and flexible planning but also highly structured project communication. In other words, agile emphasises the importance of planning, but it allows for divergence and adaptation of the course set out, hence stressing the role of flexibility in task performance of professionals (Demir 2019).

Agile project management relates to flexibility in proactive adaptation to dynamic project environments (Sanchez & Nagi, 2001). The Agile Manifesto published in 2001 presents the core ideas of agile methods[1]. This manifesto contains essential principles which emphasise individuals and interactions (instead of lengthy documentation and reports), pragmatism ('what works'), customer collaboration, and being responsive to change (Abbas, Gravel & Wills, 2008).

Abbas, Greve & Wills (2008) described agile project management as adaptive, iterative, incremental, and people-oriented, emphasizing its communicative and collaborative nature. Agile is used as a method for the *"iterative and incremental development [of] short cycle project outcomes"*, a process which requires both *"communication within the agile team and with the stakeholders"* (Malik, Sawar & Orr, 2021: 12).

Agile requires feedback engagement in task achievement, by means of communication with customers and stakeholders, but also within the team. To achieve this, Williams & Cockburn (2003) suggested that agile methods *"necessitate short "inspect-and-adapt" cycles and frequent, short feedback loops"* which help to better handle an *"industry's conflicting and unpredictable demands"*, enabling teams' complex problem-solving (Malik et al., 2021: 12).

Notably, agile encourages team reflection, i.e. teams should pose the question of what can be done better in the future and act upon/implement accordingly (Malik, Sawar & Orr, 2021; Demir 2019). This implies that using agile methods requires the exercise of professionals' metacognitive skills related to the ability to critically monitor and evaluate stakeholders' feedback as well as gauge and possibly plan for ensuing reiterations in project planning.

Research points to the benefits of agile methods for students' learning in software engineering and other engineering disciplines (Arce et al., 2022). This might be explained by the fact that agile methods provide an instrument to deal with complexity and uncertainty.

1 https://agilemanifesto.org

This is particularly relevant in real-life practice of skills. Namely, in the context of workplace learning.

Workplace learning: Using agile for (developing) adaptive performance

Longmuß & Höhne (2017) studied how agile methods facilitated workplace learning of students and found *"very encouraging results" [...] "The agile learning approach provides a focused and work-embedded learning context as opposed to traditional training courses. This allows for a tailor-made competence development that is aimed at specific future work requirements within company lines."* (pp. 266-267) Similarly, Zehr & Korte proposed that an *"important outcome of workplace learning is learning that work encompasses not only disciplinary knowledge but also adapting to ambiguity, uncertainty, complexity and social working relationships"* (Zehr & Korte, 2020). The adaptivity mentioned here links workplace learning and adaptive performance.

To clarify the role of agile in the development of students' adaptive performance, in this chapter, we examine an exemplary case of workplace learning in which engineering students use agile methods.

Analysis: The Example of Drees & Sommer SE

In this section, we examine an example of workplace learning at Drees & Sommer SE in which students acquire and apply agile project management skills. To show how agile methods enable exercise of adaptive performance during workplace learning, we draw on the Context, Intervention, Mechanism and Outcomes (CIMO) framework. We first describe the *context* focusing particularly on the learning environment. Then we address the *intervention* of the workplace-learning internship programme (its characteristics), followed by an examination of *its mechanisms and outcomes* in terms of their contribution to building students' adaptive performance. The data was collected by means of participant observation, secondary data (internal evaluations), and five interviews carried out with the project leader about this workplace learning programme.

Context

Drees & Sommer SE (Dreso) is an international consultancy company for consulting, planning, building and operating in the construction sector. In 2022, the company had more than 5100 employees at 59 international locations, made an operating result of more than 84 million, and almost two-thirds of a billion in sales[2]. Dreso has emerged from mergers and acquisitions of various smaller companies. As a result of the different company cultures Dreso brings together, Dreso seeks to standardise its work processes, but also to internationalise its business. To achieve these structural changes, Dreso has adopted agile methods in its business processes.

2 Drees & Sommer, Annual Report. Turn-over as sales. See for full report: https://cdn.dreso.com/fileadmin/media/06_Presse/Media_Center/Jahresberichte/JB_2022_01_162_en_final.pdf

Dreso considers communication skills to be crucial in construction work, e.g., for negotiation of contracts, customer acquisition, and provision of services in projects. The latter is key to avoiding miscommunication with the customer or contractors regarding the project process and outcome. Agile (project) management has proven successful in increasing customer satisfaction and decreasing time and cost to market under uncertain conditions (Ribeiro & Fernandes, 2010).

The learning environment of workplace learning analysed in this study includes large engineering projects. A large engineering project at Dreso can include over 60 contractors with their counterparts. In these projects, Dreso uses the Lean Construction Methodology (see VDI2553 or Dreso-Website), favouring synchronous communication to avoid inefficiency (misunderstandings or confusion) in the acquisition and transfer of project-related information. Lean refers to process optimalisation aimed at increasing customer value and delivery efficiency. In this case, it constitutes an example of agile work as it is aimed at flexibility and quick adaptation in project management and execution, where required.

In the exemplary case examined here, the project deals with the construction of a major railway hub with a planned construction volume of more than 540 million euros and a planned construction time of roughly 6 years. During this period, a railway station with several tracks, a connection to local public transport and the associated auxiliary structures (such as bridges, electronical interlockings, drainage structures, pedestrian subways, etc.) was built. The estimated number of passengers who are to benefit from the success of the project is about 130,000 passengers per day.

The lean construction managers on-site rely on students' tasks of obtaining, sharing, and aggregating information about the progress of the project(parts). By training students in agile project management, Dreso aims for the successful execution of large and complex construction projects, while avoiding extra work due to poorly executed project management, causing costly delays.

Students are charged with collecting and aggregating information during meetings with the stakeholders. During these meetings, information about the project (progress) is transferred and acquired, aimed at unearthing complexities which might arise, for example, from one contracted stakeholder's delay. To avoid such delays, interdependencies of time-lines must be understood by the student (teams), the building owner, its representatives, and all contractors, and continuously re-iterated.

Intervention

Students participated in the internship programme as part of a six-month full-time internship at Dreso. Other participants have temporary contracts for 16 to 20 hours a week at Dreso for varying lengths of time (some students for more than two years during their study). Both groups are informally referred to as 'interns'. Most students participating in this internship programme have an academic background in civil engineering or urban planning, some participants come from the field of industrial engineering.

At regular intervals, batches of six to eight interns start working on the examined project, with about eight students participating simultaneously at any given time. 12 students per year are involved in this programme. At the time of this study, six students from higher education engineering programmes participated in this form of workplace learning.

Students' workplace learning and agile methods-based tasks

Whether students are working in teams or only with stakeholders strongly depends on the required tasks. For example, there are tasks associated with the organisation of workshops which involve engagement with non-Dreso stakeholders. Meanwhile, the development of visuals is Dreso internal and requires collaboration only with company-internal stakeholders.

Students are expected to deal with a variety of tasks during projects. The following (non-exhaustive) list contains agile methods-based tasks which students carry out during workplace learning at Dreso:

- Development and continuous updating of visuals for the Obeya room – a collaborative workspace commonly used in lean construction projects – on the construction site, e.g., a project calendar, a visual showing the important locations on the over 3 km long construction site, and developing communication rules;
- Improvement of the project management handbook, e.g., pages explaining project specific terms and abbreviations, standardised processes such as the onboarding or the documentation process after meetings, workarounds for known software bugs;
- Development of a complex Excel sheets including VBA programming, e.g.,
  - to support the building managers and the construction companies for their reporting, and
  - to ease the invitation management for the many meetings of the project;
- Organisation of workshops. This includes the invitation management, preparation of visuals for the workshops, the follow-up documentation, supporting the moderator during the workshop, preparing the room before the workshop (so everything except doing the talking during the workshop);
- Conducting the daily standup-meetings with the construction managers and representatives of the construction companies;
- Conducting task-list meeting during which representatives of the owner are being asked to give feedback to their tasks and escalate problems if necessary.
- Improvement of the methodology according to which the daily standup-meetings are being moderated and the software tools are being used;
- Advising on internal and external process optimisation, including the visualisation and presentation of the improved processes. Once accepted by the team, the improvement for the process is being documented in the project management handbook, e.g. for conducting daily meetings or the process on how to survey and analyse Key Performance Indicators (KPI's);
- Collecting, evaluating and visualising KPIs.

The construction project is structured around regular project team meetings (from the onset throughout the project), in the setting of so-called brown paper workshops, preferably with key stakeholders being brought together in the same physical space (Backhaus, 2022; Backhaus & Dahm, 2022).

During brown paper workshops, students observe and engage with the process of the project team's joint development of the execution planning. Representatives of each trade are involved in the construction project (e.g. steel construction, earthworks, 50Hz electricians or experts for electronic interlocking) and are asked to write their processes on coloured post-its. Then the post-its are glued on the brown paper in the order of their execution to identify interdependencies (and potential issues in delays).

The brown paper workshops are preparation- and follow-up intensive endeavours. The same accounts for the regular and frequent (daily) meetings, the dailies or stand-up meetings, during which the construction planning is kept up-to-date. Materials for the brown paper and other workshops must be brought to the place of the workshop. Information which is already available must be visualised before the workshop (for instance, available schedules and known tasks can be plotted on the brown paper already written on the post-its to save time during the workshop, plans of the construction site should be plotted and brought to the workshop). Long workshops (duration of more than three hours) require a catering concept (cookies for sugar and coffee for caffeine; full meals if the workshop exceeds the duration of four hours).

During regular Dreso internal stand-up meetings, students self-organise in teams of two to six students. These teams usually last up to twee weeks, until the team members have achieved the task which they had set out for. The student teams pick their task from a task pool written on an online whiteboard. The Dreso project consultant or Dreso project team member can add tasks to the task pool, simply by writing them on the digital whiteboard. Students then pull tasks from this task pool and self-organise those tasks among themselves. During their regular stand-up meetings, students can signal issues to the project consultant which they encountered the preceding week or ask the project consultant for help with tasks.

Resources are provided to the students in the form of opportunities for reflection. The project used as example here has a weekly team meeting. During this meeting, tasks are distributed and followed up using a Kanban board, the duty roster is being completed, the personal well-being of the team is being surveyed anonymously, and support is offered afterwards, e.g., in the form of a one-on-one meeting if a team member desires guidance. Parts of this team meeting (the duty roster) are moderated by team members. One student is responsible for the organisation and improvement of the meeting (which is held online), e.g., the meeting working materials, such as visualisations used for the online whiteboard.

Every four months the project team organises a workshop around the lessons learned during the previous period. This workshop is aimed at internal process optimisation and is mandatory for all team members, i.e. mostly students. During the workshop all project team members, including

students, are asked to give feedback on internal project processes and to make suggestions for improvements. The lessons learned workshop is prepared and moderated by one of the students. During the preparatory process, the project manager offers guidance for the preparation process and during the lessons learned itself to ensure a smooth, timely and productive lessons learned workshop. During the workshop, specific improvement measures are identified and those responsible for their implementation are appointed. If the implementation of an improvement takes more than one person, the appointed responsible automatically becomes the leader of that group. After the workshop, the student who had organised the workshop has a one-on-one meeting with the project leader. During this mandatory meeting, the project leader or coach gives feedback on the students' moderating and presenting skills.

Guiding and supervision of students at Dreso

Internships at Dreso (but also all regular employment) start with a Welcome Day. In the example case, the construction project employs internship students from the area of northern Germany. The Welcome Day consists of a one-day programme during which students learn the mission, vision, and strategy of Dreso; they then get their IT equipment and learn the basic administration software and associated rules.

During the Welcome Day, the department managers from Dreso in the area are present and give a short introduction of their department to all participants. During this day, students are explicitly encouraged to network with their new colleagues – which includes both students and full-time professionals of all career levels. Furthermore, all students receive safety training, i.e. appropriate behaviour in the case of a fire.

In addition, Dreso offers a formal eight-hour training programme - the "Lean Practitioners Training" - through its own training body, the Drees and Sommer Academy. While all Dreso employees are required to partake in the training to become Lean Practitioners, the programme is mandatory for the students in the project under review. It trains the participants in lean and agile methods and prepares them to take on tasks as moderators in lean and agile workshops. To improve learning, half of the time is spent on a simulation of a typical lean and agile project. During the simulation, students take the role of contractor, owner or lean coach to build a typical structure from past Dreso projects and acquire hands-on experience in lean and agile methods.

To provide guidance and support to students in their task achievement as well as personal development, the company has designed and tests agile goals-management frameworks. These frameworks support students in the identification and formulation of personal objectives as well as key results (OKR) (Doerr, 2018; Taipel & Alberti, 2019). At the surveyed project team, such an OKR-framework is currently in the test phase.

The lean consultant also offers students business coaching. During a coaching session, the project manager explains the company goals and the resulting project goals, followed by a brainstorming session in which students offer ideas for "OKR Objectives" to support project goals as

well as key results to make the objectives measurable. An example of an objective is 'We have improved the internal coordination of the team', and an example of a key result is 'We have developed a visual overview for the weekly team meeting that shows who is responsible for which meeting, and what must be considered (e.g. online, offline, stand-in required, preparation required, etc.)'. The formulation of objectives and results also includes students' personal goals and objectives.

During quarterly OKR workshops, the student team and supervisors discuss the progress towards goals and results. During these 'lessons learned' sessions, the team also reflects on its over- as well as underachievement of tasks that had been in the goal pool. This reflective exercise per team aims at improving individual and team-based goal-achievement and -development for the following quarter.

Once a month, the company reserves an afternoon for training purposes of students. The topics vary. Examples are software trainings, e.g. cost control such as CORR (https://www.coor.info), Lean collaboration tools, such as LCMDigital (https://www.lcmd.io), and method trainings such as Lean Construction Management or Project Management trainings. These trainings are held online, connect students from all German-speaking subsidiaries of Dreso, and are often followed by a voluntary networking session in the evening.

Dreso holds additional student-specific networking events at irregular intervals. The nature of the networking event is instructional as well as social. Often the events take the form an afternoon workshop followed by a networking dinner. These events are area-specific events, either for one of the subsidiaries.

Mechanisms

Dalkin et al., (2015) proposed to study mechanism in terms of two constituent parts, namely 1) the resources offered by an intervention and 2) the ways in which this changes the reasoning (or response) of its participants. Following Dalkin et al. (2015)'s distinction, we describe both constituents of the mechanism in this section. Resource mechanism refers to the way in which Dreso provides students with practice in agile methods. Reasoning (or response) mechanism describes the way in which the resources are presumed to affect a change in students, i.e. towards the development of adaptive performance.

Resources

In terms of resources, in workshops and other meetings students learn about agile project management methods by means of applying them. From the first day onwards, students are required to interact with each other (in student teams in which students work together on more complex tasks that require various students), with their project manager, as well as other stakeholders, in sharing and aggregating information.

Students' participation in brown paper workshops provide them with practical exercise in team and stakeholder management. For one, the student team must organise itself, identifying a relevant task and how to

fulfil it. To achieve this, teams moderate up to three parallel meetings with customers and relevant stakeholders daily by themselves. Such workplace learning goes beyond the learner-teacher dyad, emphasising the role of context in which learning takes place. In addition, Dreso provides students with training in agile methods as well as substantial time for reflection and critical analysis on their own work. Specifically, the project manager organises regularly scheduled 'lessons learned' meetings, which are obligatory for all student teams and other project members.

Reasoning

Students acquire declarative and procedural knowledge on agile project management, for example, about how to structure a meeting, or how to take notes. Furthermore, this workplace learning involves frequent practice by students of communicative and collaborative skills. As Stasielowicz (2020) noted, *"dynamic environments require people to process new cues, learn new procedures, identify new strategies. Thus, abilities like processing speed or reasoning may be particularly relevant in the context of adaptation"* (Stasielowicz, 2020: p.166).

Agile project methods require students to frequently engage with other perspectives, up to three times a day, in meetings with their team or with other stakeholders. Similarly, the use of lessons learned engages students in additional dialogue and feedback situations, encouraging them to monitor and evaluate explicitly their learnings. In fact, Kim, Knag, Kim & Park (2023) found that learning practices which trigger reflection involve perspective-taking and immersion with others, notably their peer group.

Outcomes

Dreso assesses the outcomes of workplace learning during the OKR workshops, which are supplemented by a 'lessons learned' session which takes place quarterly. These workshops, as previously mentioned, are aimed at identifying issues from the previous annual quarter and reflecting on to draw learnings from them. All students working on the project (eight students) participated in the lessons learned workshop, as well as one moderator. Moderation was first done by the project leader, but the project leader reports that this has meanwhile been delegated to an experienced student. This student was instructed in how to moderate the OKR workshops.

In the OKR workshops, all eight students self-reported that practice in agile methods had helped them to improve their goal setting, planning, monitoring, evaluation, and social skills. Specifically, they described having become more confident in steering their professional development towards their personal areas of interest.

The project leader reported that students perform better than before in general project management (declarative and procedural) skills. For instance, students initiated additional retrospective meetings, which ultimately resulted in the development of an Excel tool to organise the invitation management for the many coordination meetings of the project. The tool assured that only those people were invited that had an actual role during the meeting – a task not to be underestimated considering that over 65 different contractors and their supervising

construction managers and owner representatives had to be coordinated. In another case, the student team developed a process handbook that assured that new student team members required less than 1 hour of training to produce standardised documentations of the regular coordination meetings or lean workshops. The standardisation enabled the team to produce said documentations shortly after the meetings themselves – a process which took up to three days before the standardised process had been introduced.

The project leader also noted an increase in motivation among students to see overarching global development goals, as opposed to only for smaller tasks within the organisation. For instance, after identifying a perceived mismatch between project-specific methods and the organisation's global goals, students began questioning the project's approaches and objectives. By using OKR as a platform for discussion, the team gained a deeper understanding of both its own goals and methods, as well as those of the organisation.These results indicate that practice in agile methods benefits conceptual knowledge building among engineering students – and hence, contributes to the development of their adaptive performance.

Ultimately, both the project and the organisation directly benefited from the students' input. As outsiders, students bring a fresh perspective, free from biases shaped by past project experience. This out-of-the-box thinking fosters valuable contributions, generating novel and unconventional ideas for project improvement.

Discussion

We draw two main findings from the CIMO analysis. Workplace learning using agile methods contributes to the development of students' adaptive performance by providing students with exercise in 1) perspective-taking skills and 2) meta-cognitive self-awareness skills. Both are relevant skill sets in adaptive performance. We discuss both findings in more detail below.

Perspective-taking

In line with other authors, we found that workplace learning using agile methods provides students with opportunities to learn about and take perspectives of others, specifically their team members, but also different stakeholders. Research shows that this develops students' adaptive performance (Fisher & Peterson, 2001).

We observed that workplace learning using agile methods leverages the impact of high-frequency meetings with (relevant) stakeholders and peers. Such meetings offer students recurring opportunities to seek and learn about others' interests and motivations. This provides students with frequent exercise in their ability to take others' perspectives. Such engagement with stakeholders is characteristic of agile methods, and we observed that it requires students to practice a skill which is highly relevant for adaptive performance (Fisher & Peterson, 2001).

Our findings add to extant literature by showing how workplace learning using agile methods encourages students to engage in (forms of) dialogue

with different stakeholders, i.e. with different perspectives. Kaffka et al. (2021) examined the role of perspective-taking during the development of a novel business opportunity. The authors found that perspective-taking triggers reframing of currently held understanding and beliefs, which in turn facilitates deeper-level learning among novice entrepreneurs.

Engagement in dialogue has proven to increase perceptions of usefulness of feedback and correlate positively with thinking activities among secondary education students (Van der Schaaf et al., 2011). The ability for perspective-taking is crucial for successful dialogue and reflection, as it suggests sincere engagement with feedback, necessary for transformational learning as well as for adaptive performance. For example, Kim et al.'s (2023) findings on professional learning emphasised the importance of dialogue and perspective-taking in transformational learning practices.

We propose that the variability and complexity of stakeholder engagement characteristic of agile methods contributes to building students' deeper understanding of the 'why' of a certain knowledge application. In this case, using agile methods enabled students to gain a more holistic perspective on the entire construction project. This, we argue, offers an explanation as to how agile methods support the development of students' adaptive performance.

Metacognitive self-awareness

Fisher & Peterson (2001) argued that training students' metacognitive self-awareness, i.e. monitoring and evaluation of their own learning activities, is a crucial element in developing students' adaptive performance. Metacognitive self-awareness is associated with someone's ability for learning how to learn and is highly relevant for adaptive performance (Fisher & Peterson, 2001). We propose that such practice represents a mechanism which helps explain how agile methods support the development of adaptive performance.

The variability of high-frequency meetings catalysed practice in the identification of 'atypical signals', as students prepare for, coordinate, evaluate, and report on meetings with team members, other project members or stakeholders. This provided students with practice in self-evaluative skills, such as metacognitive self-awareness. The task charts on the online whiteboard and high-frequency meetings provide students with numerous opportunities to engage with 'atypical' signals – signals from stakeholders about delays which help establish when and why to adjust project planning in large construction projects. Agile methods offer students practice in the identification of these 'atypical' signals from stakeholders.

The CIMO analysis showed that the scanning for 'atypical signals' allows students to learn to adjust their performance in response to those signals, such as making reiterations in the planning of the whole project based on novel or contradictory information. By allowing students to engage in processes of identification and categorisation of 'atypical signals' to identify issues for timely project achievement, agile methods support the building of a deeper, conceptual understanding of the whole project instead of a sole focus on one activity or task. In this way, the high-frequency meetings

used in agile methods exercised students' metacognitive skills relevant for adaptive performance. Such learning is crucial for adaptive performance (Ward et al., 2018).

While 'atypical' signals in the form of negative feedback are not always liked, they offer professionals opportunities to learn important lessons (Kaffka et al., 2021; Kaffka et al., 2024). Our findings show that the use of agile methods in workplace learning enabled students to exercise metacognitive skills. As such skills are relevant for adaptive performance, we propose that agile methods deserve a more structured place in the curriculum of engineering students.

Practical relevance

In our study, we identified three principles which aid curriculum design aimed at the development of adaptive performance among students.

One, the mechanism of high-frequency meetings and feedback interaction with various stakeholders provided students with real-world cases and contributed to perspective-taking, via dialogue in the form of high-speed meetings. Generally, research recognises the role of real-world cases and experiential education, as it offers exercise in feedback engagement, reflection, as well as complex problem-solving (Martin, Rivale, and Diller, 2007).

Two, we saw that there was room for reflection and for discussion of mistakes, which also the project leaders of Dreso take part in. Scholars have found that challenge-based learning in engineering education contributes to students' development of adaptive performance, as it offers exercise in feedback engagement, reflection, as well as complex problem-solving (Martin, Rivale, and Diller, 2007). The structural integration of collaborative reflection enables students' engagement with feedback activities. We suggest that collaborative reflection, such as occurs in agile methods, can enhance the effectiveness of engineering education in general. It prepares students for the managerial aspects of large and complex engineering projects in their future career, by developing their adaptive performance.

Three, we observed that specific educational technology - such as a shared drawing (brown) paper for brainstorming, (digital) whiteboards for task overview and monitoring - play an important part in agile methods used during workplace-based learning. For example, an online whiteboard enabled students during workplace learning at Dreso to formulate and explicate their reasoning regarding planning and monitoring of their own task but also those of one's team members. Such tools or resources can be understood as artifacts, which are relevant for task achievement among learners but also for building adaptive performance (Hatano and Oura 2003; Bailey, Winchester, and Ellies 2023).

We propose that artefacts such as visualisation tools, kanban boards, or simple flip-overs should take a more prominent place in higher education, as they provide students with tools to articulate their ideas

and engage in feedback on them. This can help to develop students' adaptive performance.

A limiting disclaimer and future research opportunities

It should be noted that scholars have identified several risks for (using/learning) agile methods in engineering projects (Williams & Cockburn, 2003), namely: (1) risk stemming from the agile approach itself, for example, design simplicity or scalability issues, (2) risks stemming from a plan-driven approach, such as constant change or need for rapid results, and (3) general environmental risks associated with technology uncertainties or engagement with diverse stakeholders. In order to design educational interventions benefiting students' learning of agile methods and training their adaptive performance, future studies can examine how risk assessment can contribute to teaching and learning of agile methods in higher education curricula.

Furthermore, the case considered in this chapter does not account for cultural differences that might arise from working with agile project management in different countries. A recent study found that feedback engagement with peers can foster dialogue and reflection essential for their transformative learning (Kim et al., 2023). Meanwhile, cultural differences have been noted with respect to uncertainty avoidance in people (Hofstede, 1980). In this sense, the cultural background of team members might affect the way that project members engage with agile methods. The iterative and open nature of agile projects, specifically frequent communication about potential issues or failures, and critical (self evaluation might feel intimidating, risky, or shameful for team members. This can jeopardise the successful application of agile methods, whether in higher education internships, traineeships, or other forms of work-based learning.

Concluding remarks

In this chapter, we analysed the role of agile project management in developing adaptive performance among construction engineering and urban planning students. We identified two mechanisms which enabled this: exercise in perspective-taking and practice of meta-cognitive skills. When students engage in dialogue and perspective-taking with stakeholders, searching for and identifying 'atypical' signals in high-frequency meetings by means of monitoring and evaluation, they develop skills relevant to adaptive performance. We propose that incorporating agile project management in education design facilitates the building of adaptive performance among students, whether in engineering programmes in higher education or beyond.

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5 | Ecology of the mind and adaptive learning

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5 | Ecology of the mind and adaptive learning

M.L. Gamborg[1], R.D. Jensen[2]

ABSTRACT **This chapter explores how adaptive expertise in engineering education can be cultivated through ecological and embodied learning approaches. Drawing on theories from ecological psychology, embodied cognition, and ecological dynamics, we argue that expertise is not solely a cognitive trait but emerges from continuous interaction between learners, their bodies, tasks, and environments. Using the recurring case of Jenny – a biomedical engineering student developing a device for coronary thrombus treatment – the chapter illustrates how adaptive expertise involves perception-action loops, motor skill acquisition, and contextual responsiveness.**

Central to the argument is the concept of ecology of mind, which frames cognition as a relational process shaped by environmental affordances and bodily experiences. The chapter challenges traditional views of motor learning as repetitive practice, instead emphasizing variability and exploration as key to developing flexible, innovative problem-solving skills. It introduces pedagogical strategies such as the PoST framework and supervision models that balance closure and discovery, supporting learners in navigating complex, real-world challenges.

By integrating ecological and embodied perspectives, we propose a holistic view of learning where cognition is enacted through doing, sensing, and adapting. This approach prepares engineering students not just to perform routine tasks but to innovate responsibly in dynamic environments. Ultimately, the chapter offers practical guidelines for educators to design learning environments that foster adaptive expertise through contextual richness, variability, and reflective supervision.

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JENNY'S CASE *Jenny is a final-year biomedical engineering student who has been tasked by her thesis supervisor to come up with an innovative way of administering treatment for coronary thrombus. The solution should be less invasive than conventional solutions and should also be cost-effective. As a part of this, she will need to develop and test her solution in a simulated setting. In this context, she will be assessing the manoeuvrability of her innovation.*
To do this, motor skills are crucial for the precise manipulation of tools and instruments during the design and prototyping phases. As her solution involves a device that requires precise manipulation within the human body, a high level of fine motor control to navigate through delicate tissues and perform intricate procedures is needed. This requires her to creatively apply and adapt solutions and innovate on current ways of administering this treatment. However, this also requires a deep understanding of how the end user will apply her solution. [1]

1 To visually distinguish this case example and highlight its relevance throughout the chapter, we have styled this scenario as a recurring case study under the name 'Jenny's Case,' which will be referenced in several sections to illustrate key concepts.

Introduction

Rather than simply memorising a great deal of information by heart, engineering education serves to teach good problem-solving skills based on a deep understanding of key concepts in engineering (Litzinger et al., 2011). Novel learners in engineering should therefore move from making surface-level connections between principles to developing more in-depth knowledge around the underlying concepts that connect these principles (Litzinger et al., 2011).

Thus, instead of teaching for knowledge through rote learning, teachers should strive to foster the development of "mental models" for key concepts within their field (Hatano, 1982; Hatano & Inagaki, 1986). Mental models help learners simulate problem-solving scenarios in their minds, enabling them to predict outcomes and adapt existing knowledge to new contexts.

A mental model should be understood as a comprehension of how something works or as an internal representation of external reality, i.e. a way of representing reality within one's mind which allows for mental simulation of how the procedure works. This allows one to make predictions or explanations about unfamiliar situations and helps when creating solutions to novel problems (Hatano & Inagaki, 1986).

This is where the concept of adaptive expertise becomes relevant. Adaptive expertise describes the ability to transfer and flexibly apply mental models to novel and complex problems. It offers a lens for under-

standing how engineers can go beyond routine practice and innovate in unfamiliar situations.

While adaptive expertise is widely recognised as a conceptual framework for understanding expert performance (Carbonell et al., 2014; Pelgrim et al., 2022), much of the foundational and developmental literature has focused on the trajectory towards becoming an adaptive expert, often emphasising growth pathways. An example is the "optimal adaptability corridor" (Bransford & Schwartz, 1999; Schwartz et al., 2005), which conceptualises adaptability as a cultivated process en route to expertise. However, in ecological psychology, behaviour is seen as an interaction between the individual and the context, and when adaptive expertise is seen from this perspective, recent research shows that even novices can employ adaptive cognitive practices (Gamborg et al., 2024). This indicates that adaptive behaviours are fairly generic competencies that we can foster early in training. This research also points to a high degree of contextuality in the ability to engage in these cognitive adaptive practices (Gamborg et al., 2023).

Historically, the exploration of adaptive expertise has focused almost exclusively on cognitive skills in isolation, largely overlooking the critical role of contextual and bodily factors in shaping expert performance. However, adaptive expertise also manifests in how individuals physically engage with their environments, for example through motor control. This in spite of the fact that research proposes that all skilled motor movement reflects components of adaptive expertise (Jensen et al., 2022).

A motor skill is a function that involves specific movements of the body's muscles to perform a task (Moini et al., 2024). Research shows that repetitive motor control is less repetitive than what is often perceived and emphasises how the inherent variability of the neuromuscular system may be leveraged to design training that promotes adaptive expertise when learning to perform motor skills (Jensen et al., 2022).

To bridge this gap, the present chapter introduces ecological cognition, grounded in the theory of perception proposed by Gibson. This perspective emphasises that expertise is not only cognitive but also embodied, arising from the continuous interaction between the learners and their environment. Cognition, from this view, is not just "in the head of the individual" but is shaped through sensorimotor engagement with the world.

JENNY'S CASE ***Ecological cognition***

In Jenny's case, her understanding of how the wire moves through simulated tissue develops not just through mental planning, but also by physically interacting with different prototypes and adjusting her movements based on feedback from the environment. These affordances guide her perception of what actions are possible.
This chapter will discuss how cognition is a function of bodily experiences. It links motor learning and adaptive expertise by arguing that adaptivity relies on affordances of the environment and that the division between cognition and motor skills seems arbitrary from this perspective.

Gibson and the theory of ecology of mind

To better understand how context and perception shape adaptive expertise, this section introduces ecological cognition – a theoretical lens that emphasises the reciprocal relationship between individuals and their environments. We begin by outlining key contributors to this perspective, including Bateson and Gibson. The term "ecological cognition" refers to how people's social and environmental context is deeply intertwined with the development of their ideas, which, in turn, influence that same context and their experiences (Bateson, 1991).

Bateson's work represents a shift in cognitive theory towards recognising the importance of context and social interaction. He argued that cognition is not a detached, internal activity, but a naturalistic phenomenon embedded within the broader ecosystem of human behaviour and interactions.
A similar line of thought is found in Gibson's ecological psychology, which emphasises how perception is a direct, action-oriented engagement with the environment (Gibson, 1979). Sekuler and Blake (2002, p.621) describe perception as the "The acquisition and processing of sensory information in order to see, hear, taste, or feel objects in the world…". Here, Gibson emphasised the importance of feedback from the perceptual field in order to move throughout our environment (Gibson, 1979). In this sense, Gibson argued for an ecological take on cognitive activity, which proposes that cognition, as a psychological endeavour, is impacted by environment, social actors, and culture, and these factors are inherently connected when we learn (Gibson, 1979; Gibson & Gibson, 1955).

Important to note here is that ecological psychology arose in the face of behaviouristic psychology which viewed psychological activities as reactions (behaviours) to external stimuli. Ecological psychology emerged as a competing thinking, positing that cognition emerges from an organism's embeddedness in its environment, viewing psychological phenomena as arising in, and moderated by the "ecology" of human existence, i.e. shaped by evolutionary, perceptual, and contextual factors. To Gibson, this ecology was a consequence of evolutionary developments in perception that allowed humans to interact with their environment by "resonating" with outside entities rather than being direct reactions to stimuli (Gibson, 1986).

Perceptual learning was thereby characterised by changes in what was perceived. This could happen either through processes of enriching existing cognitive sensory perception with something "new", or by progressively hone an ill-constructed percept into a more refined perception, that allowed for more accurate perception of the stimuli (Gibson & Gibson, 1955). In this view, perception becomes a skill: the learner "picks up" relevant environmental cues and adapts their actions accordingly.

Unlike traditional cognitive theories, ecological perspectives do not see perception as internal computation but as a relational process between organism and environment. This view implies that the environment is filled with objects that provide opportunities for cognitive events to happen. Therefore, from an ecological perspective on cognition, an individual's cognitive activities are intricately connected with their

surrounding environment where interactions with objects stimulate and support cognitive processes.

For example, problem-solving does not occur in isolation, it is informed by environmental cues, tools, and prior experiences. People do not produce a solution solely based on their rational capabilities. Instead, it happens as a function of their prior experience, leading them to imagine viable solutions and interacting with their environment for inspiration on how to adapt these experiences to the problem. Moments of insight – so-called "Aha moments" – will come as a function of prior experiences in which case current perceptions interact with past embodied experiences, allowing individuals to bridge those experiences to prompt sudden realisation of a solution to a current problem. Or experiences that are happening in-the-moment will prompt solutions to prior or lingering problems.

JENNY'S CASE ***Exploration of affordances that support adaptation***

Looking at the case in the beginning of this chapter, Jenny will use her conceptual understanding of manoeuvring a wire in areas with soft and delicate tissue when she is exploring different possibilities to access the coronary thrombosis. During this exploration, her perception of the environment will shape her actions in an adaptive manner, and her previous experiences with manoeuvring wires will help her adjust the solution to the problem at hand.

However, an important aspect of this approach to cognition is to reiterate the premise that cognitive activity is still the virtue of the individual. As Gibson argues: "Perception is an achievement of the individual, not an appearance in the theater of his consciousness" (Gibson, 1979, p. 239). While Gibson argued that perception, when seen as information pickup, does not require memory, the process of making meaning of this information pick-up does (Gibson, 1986). Here, his theory of affordances comes into place, which he defines as "...properties taken with reference to the observer." (Gibson, 1986, p.143).

Take the sensory experience of touching grass. We all know how it feels and this "knowing" provides us with idiosyncratic desires for interacting with the grass – do we like to feel it? What are our previous experiences of the properties of grass - as having visual, haptic, and practical values? Those experiences are what dictate the affordances of objects – how we perceive the object, how we engage with it, what it proposes that we can do with the object to serve our human experience.

Taken further, Gibson argued that the only relevant information there is to perceive is what we "pick up" about an object; how we make meaning of it and how we can interact with it, i.e. its affordances. Therefore, the accuracy of our perception becomes more refined with experience: "The information that is picked up... becomes more and more subtle, elaborate, and precise with practice. One can keep on learning to perceive as long as life goes on..." (Gibson, 1979, p.245).

Thus, affordances are a central component when engaging with epistemic distancing, where the learners are assessing the applicability of their current knowledge to a novel problem-solving task. Understanding perceptual activities is therefore inherent to understanding adaptive expertise, or, adaptive expert behaviours (Gamborg et al., 2024). According to Leont'ev, learning is rooted in an "orientation reflex", where the organism, through its bodily signals, commands motor behaviour as a response to the environment. These commands are then compared to inputs about the results of the actions made, and discrepancies are the object for regulating behaviour. Thereby, learning from one's experiences is both a physiological and psychological enterprise. Learning arises when input is different from the anticipated result (Leont'ev, 1978).

In the same way, adaptive expert behaviours are catalysed when we engage with something novel to us (Mylopoulos & Regehr, 2009). In this sense, learning is a situated practice that relies on ecological, sociocultural, and embodied cognitive processes, which help develop mental models of concepts. Through perceptual affordances, it creates opportunities for learners to devise innovative solutions to new problems.

In this way, cognition is a continual process of perceiving and reacting to affordances, and adaptive behaviour arises when discrepancies surface between the actual outcomes and the expected outcomes that are dictated by our previous physiological and psychological experiences. Therefore, context is paramount to the elicitation of adaptive expert behaviour, just as much as individual cognitive competence and knowledge are.

Ecology of mind and its relation to embodied cognition

To deepen our understanding of ecological cognition, we now explore how it connects to the theory of embodied cognition. This perspective highlights how our thinking is shaped by our bodily experiences: what we see, feel, and do. In his work on grounded cognition, Barsalou (2008), explains that when we think, we often mentally "replay" past experiences. These mental simulations draw on the same systems in the brain as were active during the original perception or action. In other words, our ability to think, remember, and solve problems is closely tied to how we have physically interacted with the world.

According to the theory of embodied cognition, the body impacts cognitive activities, in that, sensory experiences shape cognition. Bodily sensoria are not constraining cognitive activities, but the enactment of them (Foglia & Wilson, 2013). Importantly, knowledge structures exist and can function without sensory experiences, but bodily experiences may prompt recall of specific memories, which, in turn, can impact how one acts on knowledge (Foglia & Wilson, 2013). Thus, embodied cognition explains how adaptive practices may be shaped by sensory experience.

Embodied cognitive activities serve a functional purpose: they are directed towards solving tasks, which, in turn, are steps in broader problem-solving processes (Wilson & Golonka, 2013). This can be both helpful and impeding. On one hand, having sensory experiences can prompt cognitive activities that help innovative problem solving

by retrieving conceptual knowledge from other "mental models" and innovatively applying them to the problem at hand. However, it may also constrict problem solving to routine knowledge if this sensory input is prompting a well-known solution, which may not be appropriate to the problem at hand.

JENNY'S CASE ***Innovative insights through embodied discovery***
Jenny is watering her plants in the garden when suddenly noticing how water flows through the hose. This observation reminds her of the vascular system and sparks an idea for how to design her device to flow more smoothly through coronary arteries. Alternatively, she might glance at an old award she received for a thrombus device and reflexively try to apply that solution to her current challenge, before realising, through experimentation, that the same solution may not fit into the new anatomical and functional context.

By aligning embodied cognition with ecological cognition as posed by the theories of Gibson and Leont'ev, we highlight the interconnectedness of cognition, environment, and action. In this sense, an ecological approach to adaptive expertise adopts a more radical approach to embodied cognition, emphasizing that cognitive processes are not only influenced by bodily experiences but are co-shaped by all interactions with objects, artifacts, and other humans and animals.

JENNY'S CASE ***Innovative insights through embodied discovery***
For Jenny, each iteration with different prototypes or tool dimensions not only reshapes her hand movements but also reconfigures her understanding of how her solution will function in a clinical setting. Her learning is grounded in this continuous body-environment interaction. Every element within the environment becomes a contributor to how her thinking unfolds. For example, when Jenny experiences the flow of water while gardening, this interaction not only prompts her cognitive reflection but also informs her understanding of vascular dynamics. Her cognition emerges from this rich tapestry of interactions rather than from isolated mental representations or internalised knowledge alone.

By framing embodied cognition through the lens of adaptive expertise, it is crucial for teachers to teach learners to recognise how their environment, including tools and other human beings, influences their cognitive activities. This understanding fosters an awareness of when to rely on established routines and when to innovate.

JENNY'S CASE ***Innovative insights through embodied discovery***
The case of Jenny illustrates this well: while she may draw upon past knowledge, her interaction with her environment can lead to novel insights and solutions.

This radical perspective on embodied cognition encourages a holistic view of learning and problem-solving, where all elements of the environment are considered integral to cognitive development. Integrating these ideas into engineering education may help teachers to prepare learners to navigate complex challenges with adaptability and creativity, effectively co-creating solutions in response to their dynamic environments. By viewing adaptive expertise through ecological psychology, this chapter argues that engineering education should aim to prepare learners like Jenny to be adaptable and to engage in innovation rather than just applying a routine solution. A way of learning this is by approaching adaptive expertise as an ecology of mind, which we will explain in the next section.

Adaptive expertise as an ecology of mind

Historically, research on expertise has often emphasised how knowledge acquisition and intentional, repeated practice are the foundation for developing expert performance (Ericsson, 2004, 2015; Ericsson & Charness, 1994). Other perspectives highlight that expertise is also shaped by the specific content and context in which learning occurs, focusing on how learners build expert knowledge through experience in real-world settings (Elstein & Schwarz, 2002; Norman, 2000). In contrast to these views, this chapter argued that adaptive expertise is grounded in the dynamic interaction between cognition and context. This view expands traditional perspectives by emphasising cognitive flexibility that is applicable across domains, and highlighting the social dimensions of learning and adaptation (Moulton et al., 2007; Mylopoulos & Farhat, 2015).

The concept of adaptive expertise is strongly linked to that of distributed cognition, which proposes that cognitive activities are embedded in a social, cultural, and physical world (Hutchins, 1995). The distributed quality of cognitive activities refers to what in cultural-historical activity theory (Lave, 1988; Leont'ev, 1978) is described as a natural – or ecological – dialectic interaction between these cognitive activities and context (Hutchins, 2010). From this standpoint, adaptive expertise emerges not only from individual mental capacities but also from the interaction with social practices, tools, and environmental affordances (Gibson, 1986; Hutchins, 1995). Jenny's insights are not developed in isolation but through ongoing feedback from supervisors, her tools, and the simulated patient environment. These external factors help co-construct the design decisions she makes.

Similarly, such social aspects of learning in engineering have been described by Deters et al. (2024) as a third layer of also "knowing with", focusing on how engineers can transfer learning to other contexts by integrating and adapting experiences into new solutions. Here, learning is propelled by social exchange in collaborative learning environments, where adaptability is the sum of co-created solutions to novel problems.

Ultimately, this perspective highlights that the ability to apply knowledge adaptively is not only an individual skill, but a socially mediated competence shaped by real-time interactions with others, tools, and settings.

Adaptive expertise and motor learning in engineering

Building on the previous sections which emphasised how cognition emerges through interaction with our environment, we now turn to the role of motor learning as a key component of adaptive expertise. Motor skills not only reflect the integration of perception and action but also highlight how adaptability is enacted physically through engagement with tools, environments, and tasks.

Although motor skills are often underemphasised in engineering education, they play a crucial role in many areas of engineering practice. An example is the need for hand-eye coordination and spatial awareness when developing biomedical solutions for surgical procedures, as demonstrated in Jenny's case. In such situations, the engineer may be required to perform tasks such as implantation or other medical procedures as a step in the development or implementation of their engineered solutions. This requires the ability to foreshadow affordances of such technical equipment for surgeons, which may require engineers to acquire such motor skills. Therefore, it would be reasonable to talk about the acquisition of motor skills during biomedical engineering education.

Motor skill acquisition, also referred to as motor learning and control, is the interdisciplinary science of intention, perception, action, and calibration of the learner-environment relationship. In particular, skill acquisition is an umbrella term specific to the knowledge about which behavioural and neurological variables influence central nervous system adaptation in response to the learning of a motor skill (Magill & Anderson, 2010).

However, to make recommendations for how to implement skill acquisition in engineering education, it is imperative that we are aware of what exactly is acquired in motor skill acquisition.

JENNY'S CASE ***Motor skill acquisition***

In Jenny's case, acquisition of motor skills refers not only to mastering the manipulation of the wire but also developing a sensitivity as to how her hands respond to subtle resistance and tactile cues during practice. Her learning is not about perfect repetition, but about flexible adaptation.

This is supported by research proposing that all skilled motor movement reflects components of adaptive expertise (Jensen et al., 2022), but these movements are not simply repetitive drills. Rather, the neuro-muscular system's inherent variability can be harnessed to design training environments that foster adaptability. Repetitive motor practice, when viewed through this lens, is much less repetitive than it may appear: each iteration involves subtle adjustments and learning opportunities (Jensen et al., 2022).

Araújo and Davids (2011) emphasise that skill acquisition is primarily a process of adapting to specific performance environments. Through this adaptation, learners establish connections between perceptual information and movement – what they call functional information-movement couplings

– which are foundational to motor expertise (Araújo & Davids, 2011; Davids et al., 2012). In this view, learners are seen as adaptive systems whose behaviours emerge in response to constraints presented by tasks and environments, aligning with Gibson's ecological theory of perception (Gibson, 1979). Hence, the functional movement performed by learners in engineering during motor learning sessions is underpinned by their perceptions, intentions, and actions, which are seen as intertwined. Therefore, learning environments should allow learners to use movement variability to explore and create opportunities for action. Rather than prescribing fixed procedures, educators should enable learners to explore different motor strategies, supporting the emergence of adaptive responses (Davids et al., 2013). This emphasis on variability and interaction builds directly on the ecological and embodied frameworks discussed earlier in this chapter.

Ecological dynamics in skill acquisition and the importance of variability

To further unpack how variability supports adaptive expertise, we now turn to ecological dynamics – a framework that integrates ecological psychology with dynamical systems theory to explain how motor skills emerge in real-world settings. This perspective helps clarify how learners adapt to changing conditions by interacting with task constraints, environmental cues, and their own bodily capacities.

It builds directly on the idea that motor learning is not about repeating ideal forms but about attuning to context through perception-action couplings. Here, variability is a cornerstone in the adaptive expert framework, as Hatano writes: "…in order to acquire conceptual knowledge, it is necessary to examine systematically the effects of variations in the procedure upon the outcome." (Hatano, 1982, p.16).
Just as variability in cognitive functioning is crucial for developing adaptive expert behaviours, it is equally important in motor functioning, and thus in the way the mind and body collaborate in learning environments. Bernstein's (1967) famous statement "Repetition without repetition", highlights that no two movement patterns will ever be the same.

Therefore, it is imperative not to engage in rote, repetitive practice when leaning a new motor skill that should be applied in a dynamic and complex environment. To solve a motor problem consistently under a variety of conditions, the learner must experience as many modifications of the task as possible (Bernstein, 1967).

JENNY'S CASE ***Variation in training***

For Jenny to become proficient at understanding the manoeuvring of a wire in areas with soft and delicate tissue (such as accessing a coronary thrombosis), her training must include an understanding of these extensive variations. This may include different starting points, tissue types, and patient positions.

For example, Jenny might practice with simulations that vary the angle of vessel entry or the fragility of the surrounding tissue, helping her explore affordances and limitations of her design. These variations enable her to perceive new affordances and refine her design of the wire to accommodate motor responses in realistic, unpredictable conditions.

In sum, engineering education should recognise that adaptive expertise is not only cognitive but also embodied. Through ecologically valid and variable motor learning, learners develop the ability to understand flexible acts and develop solutions that support efficiency in complex, real-world situations.

Building on this understanding, an ecological view suggests that the acquisition of motor skills is shaped by multiple interacting constraints, including the structure and physics of the environment, the physical and mental capacities of the learner, perceptual information available through interaction, and the demands of the specific task at hand (Warren, 2006). From this integrated perspective, skill acquisition results in behaviour that is not fixed but adaptable across varying contexts. Adaptive behaviour is essential because factors such as environment, task demands, and individual goals or motivations change each time an action is performed (Davids et al., 2006). Rather than being imposed by a pre-existing plan, adaptive motor skills emerge from this confluence of constraints and real-time perception (Araújo et al., 2004).

Similarly, Davids et al. (2012) advocate for ecological dynamics when explaining motor learning. Traditional theories of motor learning focus on strengthening internal representations of movements. Researchers following this view emphasise what is acquired in memory to explain behavioural change (Hommel et al., 2001). In contrast, ecological dynamics emphasise the learners' adaptation to their environment. Rather than strengthening internal states, learners establish functional information-movement couplings, tight feedback loops between perception and action, which are foundational to adaptive motor expertise (Davids et al., 2012). In this sense, learning motor skills is shaped by the environment, the physical and mental abilities of the person, and the specific task at hand. Learners then create behaviour that adapts to different situations, by drawing on feedback from the environment which is continuously mediated by their capacities for adaptation. Instead of following a rigid plan, skilled behaviour emerges as a response to the unique demands of each task.

Building on these notions, engineering education should design learning environments that train learners' ability to align intention, perception, and action. As Araújo and Davids (2011) suggest, adaptive motor learning requires learners to continuously adjust information to their action capabilities. According to Gibson, one's actions are guided by "picking up" information detecting environmental cues that guide action. In this view, action and perception are cyclical: what we do influences what we perceive, and what we perceive shapes how we act (Gibson, 1979).

Therefore, learning tasks in engineering should be designed to include varied information – rich cues, such as changes in gap size, angles, target types, tool affordances, and positioning. These variables invite learners to engage actively with their environment, refining behaviour through repeated cycles of action and feedback. Through this, learners develop rich understandings of the environment they will have to develop solutions for, and which affordances provide opportunities for adaptations for end users.

JENNY'S CASE ***Simulated tasks, variability, and adaptation***

To prepare Jenny for developing biomedical solutions for thrombosis treatment, her educators can provide simulated tasks that reflect real-world variability. For instance, they might alter task constraints such as the material properties of tubing, the positioning of access points, or the pressure levels of simulated blood flow.

By engaging with this material and interpreting the feedback from her problem-solving process, Jenny learns to adapt, refine, and generalise her solutions across situations. Over time, this enables her to explore a range of design possibilities and improve the usability of her engineering solutions in complex clinical environments.

Educating for ecological, adaptable motor skills

The previous sections have shown that adaptive expertise is not just a cognitive trait but an embodied, context-sensitive process. Learners develop adaptive capabilities through the dynamic interplay of perception, action, and environmental feedback. We explored how ecological cognition emphasises perception-action loops, how embodied cognition underscores the importance of sensory and motor engagement, and how ecological dynamics highlight the role of variability in skill development. With this foundation, we will now discuss how educators can translate these principles into concrete pedagogical strategies.

This movement from skill acquisition to skill attunement or skill adaptation requires that the educator changes perspective and allows the learners to explore solutions rather than having them engage in repeated practice. The application of the core practice principle of "repetition without repetition" underscores the importance of adopting a transdisciplinary approach wherein each learner is positioned at the core of the educator's design endeavours (Otte et al., 2022).

To support the development of adaptive expertise, learners should be challenged to self-organise and adapt coordinative structures. Teaching for adaptability means shifting from instructing learners to perform idealised routines towards helping them interpret and respond to the nuances of dynamic tasks (Araújo & Davids, 2011; Renshaw & Chow, 2019). This highlights the importance of assessing motor behaviour in ecologically valid conditions.

In bioengineering, Ng and Button demonstrated validity evidence of a four-construct model for evaluating movement competence in a large sample of schoolchildren (Ng & Button, 2023). They found that dynamic rather than static tasks maintain the ecological condition which is representative of how users of the model interact in the real world. Through collaborative efforts, engineering educators can craft learning tasks rooted in problem-solving, tailored to address the unique requirements of individual learners. Otte et al. (2020) constructed such a training programme in sports.

The framework known as the 'Periodization of Skill Training' (referred to as the "PoST" framework) offers a valuable model for educators to design training based on an ecological approach (Otte et al., 2020).

The PoST framework outlines three progressive stages of learning:

1. **Coordination Training:** In this phase, learners explore and stabilise relationships among motor skills components. They explore various ways to execute a task and identify functional movement solutions.

2. **Skill Adaptability Training:** Here, learners are encouraged to explore various ways of performing the task, under variations in context, materials, constraints, and goals. The process of movement adaptation and optimisation helps learners refine their capacity to adapt and transfer skills to novel situations.

3. **Performance Training:** This phase focuses on preparing for and maintaining performance stability. Learners consolidate their adaptable responses and integrate performance under pressure (Otte et al., 2020).

By guiding learners through these stages, educators can scaffold experiences that support exploration, variability, and performance under changing conditions. This aligns with the ecological view that learners adapt their behaviour through ongoing perception-action loops in context-rich environments.

Here, a key educational consideration is supervision. Gamborg et al. (2022) propose a supervision framework that differentiates between two modes of instruction:

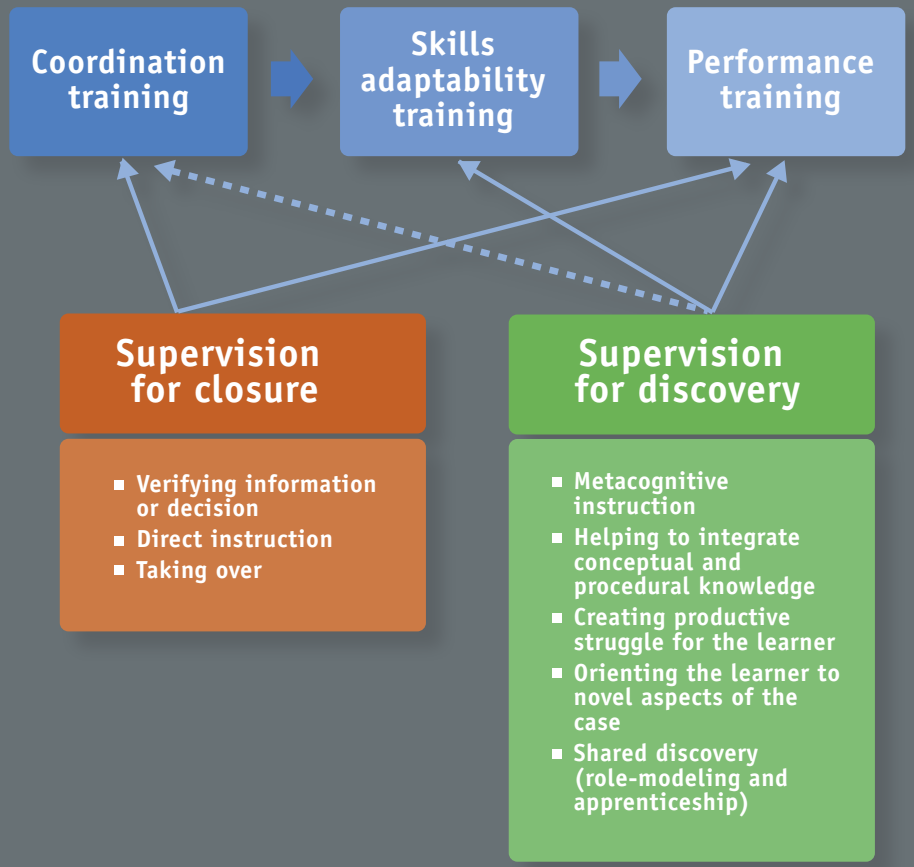
- *Closure:* When the teacher provides direct answers or instructions to a student, resulting in immediate correction, but reduced learner autonomy.

- *Discovery:* When the teacher refrains from immediate correction and instead prompts the learners to reflect, evaluate, and find their own path forward, or invite to shared learning.

In Figure 1 (p.81), we have merged the PoST framework with feedback recommendations for adaptive expertise from Gamborg et al.

The role of supervision for closure is especially important when learners are coordinating movements in the first stage of the PoST model, and

FIGURE 1 INTEGRATING THE PoST FRAMEWORK WITH SUPERVISION FOR ADAPTIVE EXPERTISE



when they are perfecting their skills in real performance environments during the third stage. On the other hand, supervision targeting discovery helps prompt learners' self-reflection and critical thinking by probing, encouraging, and role-modelling to the learners. This type of supervision is especially important during skills adaptability training and performance training to prompt further exploration of skills.

However, it can also be applied with careful intention, to the first stage, when learners exhibit trust and an eagerness to hone their skills. In this way, the figure provides strategies for how to monitor learners performing flexible tasks and provide timely and appropriate feedback. Importantly, supervision was demonstrated to be a shared, ecological practice, which impacted the outcomes of supervision. Here, the study by Gamborg et al. (2022) demonstrated that disclosing the aim of feedback and ensuring consent to approach supervision for discovery was important, as creating a safe space was essential for learners to explore and experiment in the problem-solving process.

Both approaches have value, but over-reliance on closure can limit learners' opportunities to explore and adapt. For developing adaptive expertise, discovery-based guidance is particularly valuable because it mirrors the uncertainty of real-world problem-solving.

JENNY'S CASE ***Supervising for adaptive expertise***

Returning to Jenny's case: when working with simulations to prototype a biomedical solution, her instructor might observe her technique and ask reflective questions rather than correcting errors immediately. For example, the instructor might ask "What challenges are you encountering with the current wire angle?" or "How do you think a different entry point would affect your control?". This encourages Jenny to explore affordances, adjust her strategy, and reflect on how outcomes relate to her intentions.

In conclusion, educators play a pivotal role in fostering adaptive expertise by designing tasks that incorporate variability, encouraging exploratory learning, and modulating supervision strategies. Not only do these practices help learners acquire skills, they also cultivate the flexibility to apply them in novel and unpredictable contexts, a hallmark of adaptive expertise.

Summary and practical guidelines

This chapter argues that adaptive expertise in engineering education is not solely a cognitive endeavour. Rather, it is a dynamic process shaped through continuous interaction between the learners, their body, the task at hand, and the surrounding environment. Drawing from theories of ecological cognition, embodied cognition, and ecological dynamics, we have shown how adaptive expertise emerges when learners engage in perception-action loops, respond to affordances, and practice within variable, context-rich environments.

In engineering education, embodied approaches to learning can enhance the development of sensorimotor schemas, crucial for tasks requiring precision and adaptability, such as biomedical device prototyping or robotics. By simulating real-world conditions that engineers will face, these approaches allow learners to integrate perception, action, and environmental feedback.

JENNY'S CASE ***Simulation in engineering with variability and embodied cognitive adaptation***

If we take the example of Jenny, her task involves manipulation of surgical tools or mechanical components. To support her learning, educators might provide her with prototypes of varying material stiffness and observe how she adapts her techniques. Here, teaching her to do so can be designed with variable constraints (e.g. different materials, positions, or tools), encouraging her to adapt her movements and refine motor skills. This adaptability fosters not only technical competence but also the ability to innovate under changing conditions, essential for solving complex engineering problems. Such embodied learning helps engineers form functional connections between their actions and environmental cues, improving their ability to apply their designs in practical settings.

By shifting focus from mental representations to embodied action and perception, we propose a more holistic view of learning. This view acknowledges that expertise develops not just in the mind but through doing – through acting, sensing, adjusting, and reflecting within specific environments. Educators should design tasks that simulate real-world scenarios, ensuring that learners interact with dynamic variables such as tool manipulation, material properties, and spatial constraints. For example, biomedical engineering learners can engage in hands-on problem-solving activities where motor skills, like for instance hand-eye coordination, are tested in complex environments such as simulating surgical procedures.

Teaching should emphasise variability in tasks to foster adaptability, a key feature of adaptive expertise. Encouraging learners to explore different solutions rather than repetitive practice enables them to develop a deeper understanding of how motor skills and cognitive processes intertwine.

Supervision strategies can shift between providing direct feedback for skill refinement and encouraging self-discovery for innovative problem-solving.

To support the development of adaptive expertise in engineering learners, we offer the following practical guidelines, based on the ecological and embodied learning approach:

1. **Design contextual richness and variability and ensure representativeness of the performance environment:** Design learning tasks that closely represent the complexity of real-world conditions which engineers will face, with changing materials, tools, and constraints. This allows learners to engage with diverse affordances and practice adjusting their actions accordingly. For example, in biomedical engineering, tasks like tool manipulation in simulated surgeries can create realistic scenarios which reflect the challenges that the end users encounter in their professional environments and promote adaptive problem solving within learners.

2. **Emphasise exploration over repetition:** Encourage learners to try different strategies rather than repeating idealised techniques. Incorporate diverse task constraints to promote adaptability. Variation fosters learning through adaptation rather than memorisation, encourages learners to explore different solutions, and enhances their ability to innovate under changing conditions, elicited by these embodied experiences during the engineering process.

3. **Foster perception-action awareness:** Help learners become more attuned to how their actions influence and are influenced by environmental feedback. This helps learners to become aware of idiosyncratic affordances that can help or impede skill development and innovative problem solving, fostering a deeper understanding of task dynamics. This can be supported through discussion, debriefing, and reflective supervision.

4. **Encourage embodied sense-making:** Support learners in recognising how their physical interactions with tools, materials, and bodies contribute to insight and innovation. Reflection on sensory and motor experiences should be integrated into design and problem-solving processes.

5. **Utilise supervision to balance closure and discovery:** Provide feedback that guide learners, when necessary (closure), but also allows space for exploration, decision-making, and reflection (discovery). This balanced approach helps learners develop both precise motor skills and adaptive, innovative thinking.

Through these practices, educators can support learners like Jenny in developing the flexible, responsive, and context-sensitive competencies that define adaptive expertise. In doing so, engineering education becomes not only a training ground for technical skill, but a space for cultivating the ecological intelligence needed to develop and implement solutions for the 21st century that support navigating complexity and innovating responsibly.

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6 | Empowering university educators
How Q-sorting fosters adaptive expertise and professional development

Photo: Anastasiia Nelen | Unsplash

6 | Empowering university educators
How Q-sorting fosters adaptive expertise and professional development

L. van Bruggen[1], H.J.M. Pennings[2], D. Georgiou[3]

ABSTRACT **Teaching is a complex and often unpredictable profession that requires both routine and adaptive expertise. Structured reflection might play a key role in developing adaptive expertise; however, opportunities for such reflection are not always embedded in professional development programmes.**

In this chapter, we share our experience using the Q-methodology, both as a research tool and as a way to engage university educators in meaningful discussions about the challenges they face in their (innovative) teaching practice.

We conducted seven Q-sorting workshops with a total of N = 93 university educators from various disciplines and countries, in which we invited participants to rank classroom challenges and reflect on their experiences. Our shared experiences, along with participant feedback, revealed that the Q-sorting method fostered rich conversations, supporting participants to gain new insights, exchange teaching strategies, and identify shared challenges. University educators reported in their feedback that the Q-sorting activity was engaging and insightful, highlighting the importance of structured reflection in professional growth.

We believe that integrating Q-sorting into teacher professional development programmes could provide a practical and engaging way to empower educators in transitioning from routine to adaptive experts. Discussions around real-world teaching challenges can encourage both individual and collective learning, supporting educators to better navigate the complexities of their profession with confidence and flexibility.

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Introduction

Teaching is a complex profession (Flores, 2017), and becoming a teacher can be challenging in many ways, especially for those transitioning from content expertise to teaching. This shift often requires developing new skills, such as pedagogical strategies and classroom management, that go beyond subject knowledge. In teaching, flexibility and adaptivity are required almost every day. Yet, large parts of teaching require more routine expertise or become routine over time. For example, handling students who arrive late, managing disrespectful behaviour, or addressing common classroom disruptions often becomes second nature as teachers gain experience. These routines allow educators to focus their energy on more complex and unpredictable aspects of their work, such as tailoring lessons to individual needs or navigating challenging teaching moments.

In an ever-changing world, the need for adaptivity is becoming increasingly crucial across all professions, including education. In Higher Education, the development of adaptive expertise in students depends significantly on teachers who model flexibility and adaptivity

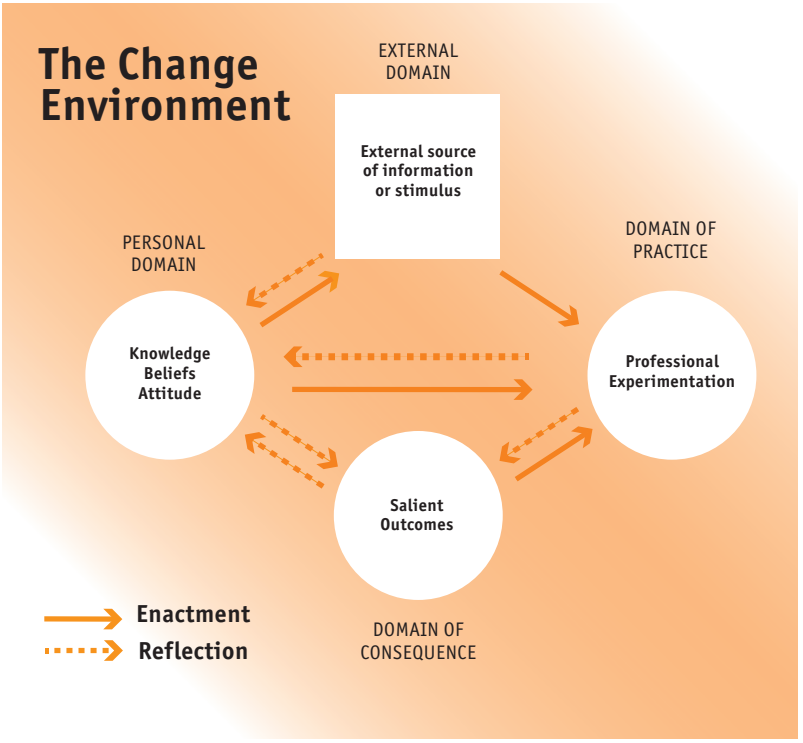


FIGURE 1 THE INTERCONNECTED MODEL OF PROFESSIONAL GROWTH (CLARKE & HOLLINGSWORTH, 2002)

in their teaching practices (e.g., Lunenberg et al., 2007; Moore & Bell, 2019). Adaptive expertise and adaptive performance are often considered interchangeable or, at the very least, closely related concepts (Bohle Carbonell et al., 2014; Kua et al., 2021). There is, however, a difference. In our research, we adhere to the definitions as provided by Pelgrim and colleagues (2022), stating that "adaptive performance is best referred to as the visible expression of an adaptive expert".

In other words, adaptive performance is the observable behaviour that requires adaptive expertise to be demonstrated (Pelgrim et al., 2022). Adaptive performance is triggered by a 'change' that may be new to the world (e.g., COVID-19) or to the individual (e.g., experiencing teaching situations for the first time). How a person responds to this change depends on their level of maturity, which in our research refers to their professional development as a teacher.

Expertise is not innate; rather, it is cultivated through deliberate practice (Ericsson et al., 2018) and structured reflection, which help educators navigate the complexities of teaching in dynamic environments. As shown in Figure 1, Clarke and Hollingsworth's Interconnected Model of Professional Growth (2002, p. 951) captures the intricate process of teacher development by emphasizing the interplay of enactment and reflection across four interconnected domains: 1) the personal domain (knowledge, beliefs, and attitudes), 2) the domain of consequence (teaching outcomes), 3) the external domain (institutional context), and 4) the domain of practice (professional experimentation). This model highlights that growth and change occur within a constantly shifting environment, underscoring the importance of reflective practices and deliberate efforts to adapt and evolve as educators.

However, what becomes routine and what still requires adaptive performance can vary significantly depending on a teacher's career stage (Van Tartwijk et al. 2023). Competency frameworks for teaching in Higher Education, such as the UNITE framework by Van Dijk and colleagues (2022), highlight the importance of continuous professional development. These frameworks stress the need for a dynamic learning process that includes stage-appropriate challenges to foster adaptive teaching skills effectively.

The challenges faced by individual teachers are often highly personal, and there is limited knowledge about which situations are commonly regarded as challenging across the profession. To address this gap, we conducted a study using Q-methodology to explore the challenges university teachers regard as requiring adaptive performance and to examine whether these challenges differ between novice and more experienced university teachers. The goal of this chapter is twofold: to provide valuable insights into the application of the Q-sorting method for data collection and to demonstrate its potential for fostering personal and collaborative reflection on teaching practices, adaptivity, and professional development.

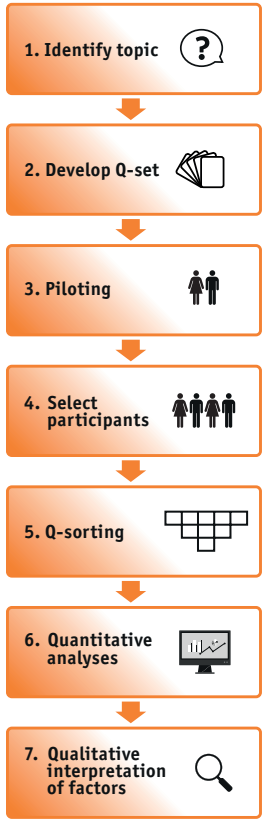
The Q-Sorting method

William Stephenson introduced Q-methodology in 1935 as a new, practical method that combines quantitative and qualitative methods to explore people's perspectives on specific topics, such as attitudes toward political ideologies or preferences in teaching methods (Bashatah, 2016). The foundation of Q-methodology is the idea of subjectivity, which is based on or influenced by individual opinions. This method aims to understand how individuals perceive a topic based on their unique experiences, values, and beliefs rather than measuring objective facts. By focusing on personal perspectives, Q-methodology captures the diversity of opinions on complex issues like teaching practices, healthcare policies, or social matters.

In Q-methodology, data is collected qualitatively but analysed statistically, blending qualitative depth with quantitative rigour. Unlike traditional tests, it correlates participants (P-set) based on their reactions, treating these as factors. The core tool of Q-methodology is the Q-sorting method, a structured framework where participants rank-order statements (Q-set) according to their firsthand experiences and beliefs (Jedeloo & Van Staa, 2009).

The Q-sorting process involves several stages, as presented in Figure 2 (Churruca et al., 2021, p.2). Designing the statements, known as the Q-set, is particularly critical to ensure relevance and clarity. Participants, ideally numbering between 40 and 60, sort the statements using a forced-choice distribution on a fixed quasi-normal grid (Bashatah, 2016). During or after sorting, participants often provide added input through think-aloud protocols or follow-up interviews to contextualise their choices and share their broader perspectives.

FIGURE 2 STAGES OF Q-METHODOLOGY, CHURRUCA ET AL. BMC MED RES METHODOL (2021) 21:125. P.2



The quantitative analysis of Q-sets is done in specialised software, such as Q-method software (https://qmethodsoftware.com). The quantitative analysis underlying the Q-methodology is based on factor analysis. Regular exploratory of confirmatory factor analysis relies on identifying patterns in items of a questionnaire, through analysing correlations between these items. This type of factor analysis is referred to as the R-methodology (Morea, 2022). In Q-methodology, factor analysis is used somewhat differently. The analysis of Q-methodology relies on correlations between the entire Q-sets of the participants. Thus, instead of correlating each

statement with the other statements, it correlates the entire Q-set of statements to the other Q-sets (Morea, 2022). Based on all the correlations, several factors are extracted on which the Q-sets load. The factors with the highest factor loadings are selected based on significance levels and used to interpret the factors. Interpretation of the factors is mainly done through comparing distinguishing (i.e., statements significantly different between factors) and consensus statements (i.e., statements that are similar across factors; Morea, 2022).

Q-methodology has notable strengths. It offers a structured way to explore subjective viewpoints, allowing participants to express their perspectives without the constraint of *right or wrong* answers (Morea, 2022). The method encourages all voices to be represented and often fosters deeper reflection among respondents, who in general enjoy the interactive process.

Despite its origins a century ago, Q-methodology gained broader application around the turn of the millennium. It has been employed in diverse fields including politics (Brown, 1980, as cited in Bashatah, 2016), nursing research (Akhtar-Danesh et al., 2008), and healthcare research (Churruca et al., 2021). It has also been used to investigate the hidden curriculum in clinical workplaces (Mulder et al., 2019). However, to our knowledge, it has not yet been applied specifically in teacher development programmes, offering an opportunity to explore its potential in this context.

Q-sorting workshop

In our research, we used Q-methodology to explore which challenges university teachers identify as requiring adaptivity and out-of-the-box thinking and whether these challenges differ between novice and experienced educators. Through interviews with experienced and novice university teachers combined with our own experience as teachers, we identified 23 common challenges in teaching practice. These were then formulated as statements in the Q-set. The cards in the Q-set were double-sided and presented the statements in English on one side and Dutch on the other side for participants to choose their preferred language. A few examples of statement cards are presented in Table 1 (p.93).

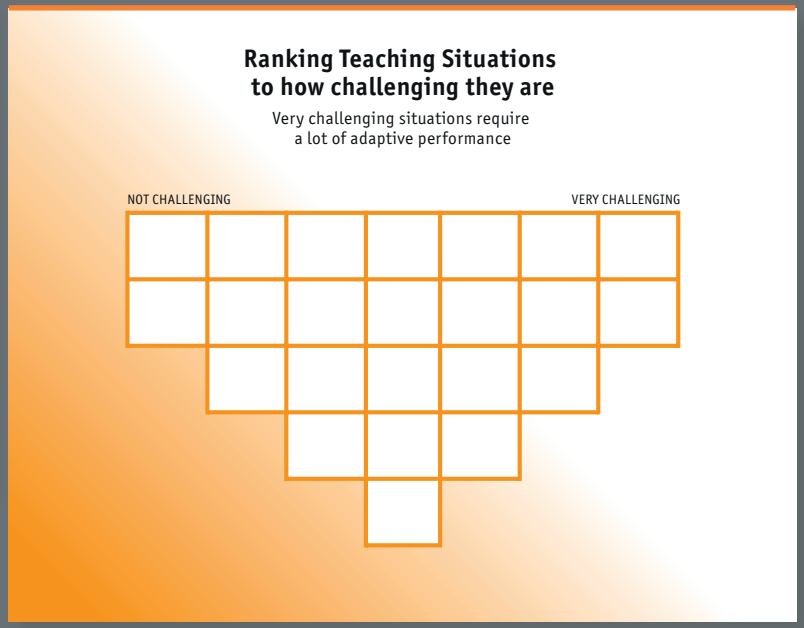
The Q-method was implemented in a workshop setting, beginning with a brief presentation (≈15 minutes) on our research and the concept of adaptive expertise. Teachers were then asked to prioritise the 23 situations based on how challenging they found them individually. This was done by sorting cards (in silence) on a grid (≈20 minutes), with “not challenging at all” and “very challenging” as the end points in the grid, see Figure 3 (p.93). The grid required participants to choose two situations as the most challenging and two as the least challenging.

As a last step, participants discussed their rankings in small groups (≈20 minutes), reflecting on the similarities and differences in their choices and explaining why they found certain situations more challenging than others (see Figures 4 and 5 (p.95)). This exercise

TABLE 1 EXAMPLES OF THE STATEMENTS IN THE Q-SET

Statement card
A student gets angry during group work and leaves the room smashing the door.
A student enters class with a plate of hot food and starts eating very noisily.
A student asks a question beyond the content expertise of the teacher.
During online teaching, Teams loses the connection. Students post disrespectful content via an online voting tool during class.
One student does not collaborate on the group assignment.
Due to the noise of construction works nearby students cannot hear you.

FIGURE 3 Q-SORTING GRID USED DURING WORKSHOPS



encouraged reflection on which teaching activities and challenges require adaptive expertise. Through shared experiences, participants revealed whether they had encountered the situations and how they had responded.

The workshop concluded with a plenary wrap-up (≈15 minutes) where we collaboratively narrowed the challenges down to a top 5 list. This list aims to serve as a foundation for developing training scenarios to support teachers in tackling these challenges and improving their (future) teaching practice.

The workshop was facilitated by members of the research group who were also expert trainers. We documented the individual rankings using photographs of the grids and recorded the subgroup discussions. Participants provided demographic information, including their professional role (e.g., teacher, policymaker), age, years of teaching experience, and the country in which they teach. During the introduction, we presented a QR code and asked participants to sign the informed consent form, granting permission to use their data.

In conducting the first Q-sorting workshops, we aimed not only to collect data but also to observe how the method could foster reflection among participants on their teaching practices. The first group of 33 participants varied in their teaching experience, ages, and perspectives (teacher, educationalist, etc), but all were involved in Health Professions Education, with a shared passion for teaching. The second group of 11 participants varied in teaching experience, age and country but shared the perspective of being a teacher in Higher Education. In total, we conducted seven workshops with a total of N=93 participants.

Our experience and lessons learned

From both the collected data and the workshop experience, we learned that Q-sorting serves not only as a data collection instrument but also as a powerful tool that can guide teachers through both individual and shared reflection on their teaching practices. As outlined in the literature and presented in chapter 1 of this book, adaptive expertise and adaptive performance are crucial for navigating the unpredictable aspects of teaching (Pelgrim et al., 2022), and our findings aligned with this. However, while some situations certainly require flexibility and adaptability from the teacher, to call that adaptive performance may be going a bit too far.

Insights from participants' reactions

The Q-sorting exercise allowed teachers to reflect deeply on what they find challenging in their teaching and helped them uncover personal insights into their teaching practices. This might not happen in traditional teacher development sessions. For example, one participant shared how they struggled with balancing diverse student needs in large classes, which was something they had never discussed in detail with colleagues before.

Through the sorting process, they were able to prioritise this challenge and later reflect on strategies for addressing it. Or, as another example,

one participant realised that they considered a situation of a physical fight not challenging in the former psychiatry workplace when being a nurse, but very challenging in the role of the teacher if it concerns two students in a classroom.

Through Q-sorting, participants not only named what they found most challenging in their teaching but also engaged in meaningful conversations with peers about how to address these challenges. For instance, several participants reported how they felt comforted by the fact that other colleagues faced similar challenges and insecurities around those situations linked to their responsibilities as teachers. Automatically, the more experienced teachers started to advise starting teachers while sharing their stories.

These kinds of insights represent the ongoing professional development that structured reflection facilitates (Clarke & Hollingsworth, 2002), supporting the development of adaptive expertise as teachers learn to tackle unforeseen challenges.

Besides the valuable personal insights that participants obtained from the individual part of the Q-sorting exercise and the supportive discussions in the shared reflection, participants also experienced Q-sorting as 'fun to do'. Which we believe is a very positive sign if you want to use Q-sorting not only as a research tool but also as an instrument to involve teachers in structured reflection activities to further develop their (adaptive) expertise.

FIGURES 4 AND 5 FIRST WORKSHOP USING Q-SORTING. NVMO-CONFERENCE 2024, NETHERLANDS (OWN PHOTOS)

The dual role of Q-sorting: Research and professional development tool

Developed as a data collection instrument, Q-sorting should, in the first place, be considered a research method. But combining the sorting exercise with discussion among peers turns it into a professional development tool that can help start a shared reflection.

This shared reflection process can be stimulated by giving participants clear questions to address within their group discussions. For example, we asked them to discuss the two situations they ranked most challenging and explain to each other why they consider those to be so challenging. This helped participants to reflect and to engage in discussions with peers and automatically evolved into sharing firsthand experiences with situations like those on the cards and providing tips and tricks to each other, as mentioned before.

If challenges are addressed in the regular professional development of teachers, like trajectories for obtaining teaching qualifications, they often derive from topics like the use of didactic approaches or constructive alignment issues. Addressing firsthand experiences with challenges in classroom management or student interaction is not always common. Using a Q-sorting exercise, for example, with a smaller Q-set and varying cards, can stimulate shared reflection and maybe turn it into the 'good habit' of ongoing reflective process like Ericsson and colleagues (2018) mentioned.

When used with discussing the results among participants, the Q-sorting method goes beyond a data collection method. It can be a valuable instrument for future faculty development to stimulate shared reflection among teachers about their teaching practices.

Conclusion

Student curricula are increasingly moving in the direction of collaborative learning, providing new challenges for teachers. Current teacher development offerings often focus on dealing with common situations in teaching and things a teacher can prepare in advance. To become adaptive experts in education, teachers must navigate unforeseen challenges beyond their routine responsibilities, requiring innovative professional development efforts.

The Q-sorting method offers a structured framework for teachers of varying experience levels to guide both individual and shared reflection on their teaching practices. Incorporating regularly structured shared reflection moments using tools like Q-sorting in faculty development programmes might help teachers foster the development of their (adaptive) expertise in teaching.

Authors note

For writing this chapter, we were inspired by the Personal View article format of the Journal *Medical Teacher*, which is an article type that presents and reflects the authors' firsthand experiences or viewpoints on a relevant topic.

Ethical approval

The present study received approval from the Ethics Review Board of the Faculty of Social and Behavioural Sciences at Utrecht University under number 23-0430 in November 2023. All participants provided written informed consent to take part in this study.

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7 | Building engineering students' adaptive performance through challenge-based learning: A sensemaking perspective

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7 | Building engineering students' adaptive performance through challenge-based learning: a sensemaking perspective

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ABSTRACT

This study seeks to provide insights into micro-level processes which help explain how challenge-based learning (CBL) supports development of adaptive performance among students in higher education. Based on empirical data and using the sensemaking perspective, we analyse how educational design of CBL enables and develops adaptive performance among engineering students.

We show that, in addition to task- and curriculum-related factors, there are important contextual factors in education design supportive of adaptive performance development. Specifically, a safe learning environment and informal interaction with teaching staff contribute to this.

We found that such an environment allows students to engage in (negative) feedback loops using sensegiving, sensedemanding, and sensebreaking. These sensemaking skills constitute collaborative discourse relevant for development of adaptive performance in higher education.

Our findings indicate that practice of sensegiving, sensedemanding, and sensebreaking during CBL helps to develop students' adaptive performance. Namely, by enabling students' use of questions as well as their engagement with (negative) feedback within and outside the classroom, such as with a challenge-owner or relevant stakeholders.

Furthermore, we argue that sensegiving, sensedemanding, and sensebreaking can serve as empirical indicators for assessment of adaptive performance development among students in higher education and beyond.

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Introduction

Adaptive performance describes professionals' task achievement under conditions of novelty or uncertainty (Pelgrim et al., 2022). Because firms seek such adaptive professionals (Nandini, Gustomo, & Sushandoyo, 2022), the development of adaptive performance in higher education has received interest from academic research (Kua et al., 2021).

Scholars have identified diverse elements of educational design which can help to build students' adaptive performance in higher education (Streveler et al., 2008; Carbonell et al., 2014; Kua et al., 2021). In recent years, challenge-based learning has gained traction in higher education (Leijon et al., 2022). Challenge-based learning (CBL) is an educational strategy which combines content learning with interdisciplinarity, stakeholder engagement, and real-life, non-routine problem-solving tasks (Membrillo-Hernandez, 2019; Van den Beemt et al., 2023; Doulougeri et al., 2024).

Challenge-based learning is associated with the development of adaptive performance in education (Carbonell et al., 2014; Kua et al., 2021), also among engineering students in higher education (Van den Beemt et al., 2023). Meanwhile, there is a lack of detailed qualitative methodologies to study micro-level mechanisms by which adaptive performance development in higher education occurs (Gallagher & Savage, 2023). This is problematic as it impedes optimal design of educational interventions, such as CBL, which are aimed at training adaptive performance in higher education. Hence, clarifying the micro-level mechanisms by which CBL affects development of adaptive performance among higher education students merits closer attention.

In this chapter, we examine how educational design of CBL enables and develops adaptive performance among engineering students in higher education. This yields the following research question: *How does challenge-based learning support engineering students' adaptive performance (development) in higher education?*

We carried out a qualitative, explorative study among students participating in an educational programme which uses CBL at a technical university in the Netherlands. To answer our research question, we examined how challenge-based learning design enables students' use of sensegiving, sensebreaking, and sensedemanding. Various studies show that these three sensemaking processes are associated with adaptive performance of professionals (Randall et al., 2011; Sparr et al., 2022; Kaffka et al., 2024). We propose that they facilitate conceptualisation and micro-level analysis of how CBL design enables and develops adaptive performance.

We start this chapter with an introduction of adaptive performance, its development in higher education, as well as a description of challenge-based learning. Then we present the sensemaking perspective and zoom in on the processes of sensegiving, sensedemanding, and sensebreaking. We demonstrate how these three sensemaking processes function as mechanisms which enable and develop adaptive performance in CBL in engineering education. We then present the key findings of our analysis, discuss their contributions to the literature, practical implications, and end with a short conclusion.

Adaptive performance

Adaptive performance describes professionals' ability to handle work stress, solve problems creatively, possess, have superior interpersonal adaptability skills, and a learning orientation (Pulakos et al., 2000; Charbonnier-Voirin & Roussel 2012; Pelgrim et al., 2022). For example, adaptive performance occurs when professionals make more effective use of resources or invent new procedures to support learning and problem solving in practice (Mypolous et al., 2018).

Adaptive performance and conceptual knowledge

Conceptual knowledge goes beyond content knowledge which describes declarative ('what') and procedural ('how to') knowledge (Hatano & Inagaki, 1984). Conceptual knowledge is a person's understanding of when and why to transfer domain-related declarative and procedural knowledge (Streveler et al., 2008; Baard et al., 2014). Conceptual knowledge refers to knowing why a concept or skill works in novel or uncertain situations. It forms the base for professionals' adaptive performance (Myopoulos et al., 2017).

Traditionally, engineering faculties transfer declarative ('what') and procedural ('how to') knowledge to their students. Declarative and procedural knowledge yield students with speed and accuracy in domain-relevant tasks, described as routine or content mastery (Clegg & Diller, 2019). This focus on context expertise in engineering education has been criticised, as it might come at the detriment of developing students' conceptual knowledge base (Hicks et al., 2014).

Development of adaptive performance

Extant work shows that there are design elements which relate to context, curriculum, or task (learning activity), which facilitate development of conceptual knowledge among higher education students. Below, we elaborate on their role in adaptive performance development in higher education.

Design of educational context

In their research on adaptive performance in relation to higher education, Kua et al (2021) noted that social and physical context play an important role for development of adaptive performance. Other authors agree that safe learning environments have a general effect on preparedness to innovate and be creative, which form crucial dimensions of adaptive performance (Gube & Lajoe, 2020). A socially and physically safe context yields an environment suitable for collaborative discourse,

meaning student-centred discourse which elicits students' engagement and reflection by means of questions (Bowers et al., 2020).

A positive error condition relates to educational design, which allows for experimentation, negative feedback, or failure. Research shows that a positive error condition helps to build adaptive performance among students. A study showed that it is important to build a space where students are safe to experiment and to engage in (negative) feedback (Charbonnier-Voirin & Roussel, 2012). Similarly, Gube & Lajoie (2020) describe educational design which contributes to adaptive performance as being supportive of productive failure, as it encourages creative thinking and supports mastery of goals.

Design of curriculum

Adaptive performance can be developed with active learning activities which promote a learning orientation (Bransford & Schwarz, 1999). To build adaptive performance, scholars have advocated that higher education should (1) emphasise understanding rather than performance, (2) offer opportunities for struggle, risk taking, and failure, and (3) be coupled with opportunities for meaningful variation around conceptual or procedural knowledge (Bransford & Schwarz, 1999; Myopolous et al., 2017).

Exposing students to struggle, risk taking, and failure by means of guided discovery (Kua et al., 2021) is known to support development of conceptual knowledge (Myopolous et al., 2017). The concept of guided discovery describes supportive information in the form of feedback as well as reflection on how things are organised and how tasks are best approached, i.e. cognitive strategies (Bohle Carbonell & Van Merriënboer, 2019).

Guided discovery enables students to critically reflect on the quality of both personal problem-solving processes, which is relevant for development of adaptive performance (Carbonell et al., 2014). Giving students a certain degree of freedom in task selection and letting them explore possible solutions and relationships between solutions and goals that can be reached with them, as well as making errors in an environment where it's safe to make them, all contribute to developing students' adaptive performance (Carbonell et al., 2014).

Design of learning tasks

Task variety and task complexity are crucial for building adaptive performance among students (Van der Schaaf et al., 2020; Kua et al., 2021). Bohle Carbonell et al. (2014) also suggest that using open learning tasks and simulated task environments develops adaptive performance in higher education.

To support students' learning optimally, scholars recommend guided discovery, the use of flexibility-focused feedback related to methods to acquire knowledge, including the use of mentoring, to stretch students' skills (Ward et al., 2018). These feedback methods, which put an emphasis on learning, require students' reflection as well as

their engagement in different perspectives while critically examining and identifying and articulating their own perspective and learning process.

Notably, reflection and engagement in different perspectives have been identified as relevant for building students' adaptive performance (Fisher & Peterson, 2001).

Challenge-based learning

A CBL-based curriculum involves innovative strategies on how to apply the students' technical knowledge (Clegg & Diller, 2019). CBL is characterised by inter- or multi-disciplinarity, stakeholder interaction, and an open, flexible, learner-centred pedagogical strategy (Membrillo-Hernández et al., 2019; Van den Beemt et al., 2023; Gallagher & Savage, 2023; Doulougeri et al., 2024).

Like other active learning experiences, challenge-based learning emphasises students' agency and self-directed learning (Doulougeri et al., 2024). CBL revolves around a challenge, often societal (for example, concerning issues of sustainability, energy, or public safety), and always involving a challenge-owner. A challenge-owner is crucial in CBL as this vouches for students' learning from a real-life issue Membrillo-Hernández et al., 2019). CBL is regarded as one of the most engaging and personal growth-oriented active learning approaches at present (Irani, 2015). For example, Clegg & Diller (2019) found that students identified challenge-based pedagogies as their preferred methods of classroom instruction.

Research shows that CBL facilitates learning in several ways. Benefits of CBL for students are identified as the application of skills in a real-world environment, such as training in multidisciplinary teamwork, conflict resolution, and communication, problem solving and innovative thinking, as well as technical skills, and achieving a deeper understanding of knowledge (Membrillo-Hernández et al., 2019; Gallagher & Savage, 2023).

We know that CBL can support skills development relevant for adaptive performance, such as collaborative and innovative skills (Gallagher & Savage, 2023) which are essential for adaptive performance of professionals.
Extant work points to the usefulness of CBL in the context of engineering students (Doulougeri et al., 2024). However, we know little about the micro-level processes which help explain how CBL enables and develops adaptive performance among students in higher education. To study development of adaptive performance during CBL on the micro-level of individual students, we draw on the sensemaking perspective.

Sensemaking perspective

Sensemaking relates to processes of meaning-making in situational or task uncertainty and/or novelty, serving purposes of both interpretation and action (Weick 1995). It encompasses individuals' cognitive efforts in detecting, labelling, and categorising information (Weick et al., 2005). Sensemaking plays a key role in the cognition of adaptive performance of professionals (Klein et al., 2007; Ward et al., 2018).

Notably, research shows that (shared) sensemaking plays an important role in a team's adaptive performance (Randall et al., 2011; Sparr et al., 2022). The literature distinguishes between different sensemaking processes which enable adaptive performance in shared, i.e. collaborative, task achievement. Namely, sensegiving, sensedemanding and sensebreaking.

These three socially situated sensemaking processes function as mechanisms which allow professionals to engage with others in successful task achievement under conditions of novelty and uncertainty (Kaffka et al, 2021; Kaffka et al., 2024). We briefly describe each of these three mechanisms.

Sensegiving

Sensegiving describes all effort directed towards achieving shared meaning (Hill & Levenhagen, 1995; Weick, 2005). Sensegiving is the most common sensemaking process by individuals to reduce equivocality and ambiguity of a situation. It consists of *"offering descriptions and explanations, providing signals, constructing credible and consistent narratives, and projecting images through stories, slogans, metaphors, and artifacts"* (Vlaar et al., 2008: p. 240). Studies show that sensegiving, such as narrative framing, enables shared meaning-making under conditions of uncertainty or novelty of task or context by use of symbols and shared meaning (Zott & Huy, 2007; Cornelissen, Clarke, & Cienki, 2012; Day, Balugon & Mayer, 2023).

Sensedemanding

Sensedemanding relates to all efforts made by individuals to acquire and process novel information. Like sensegiving, sensedemanding aims to establish 'a manageable level of uncertainty', in terms of reducing the equivocality or ambiguity of a situation or task by improving the quality of information upon which someone can base their decisions (Vlaar et al., 2008). Sensedemanding involves the asking of questions, performing inquiries, and cross-checking one's own perceptions and interpretations with other individuals, including participants of other organisations (Vlaar et al., 2008; Kaffka & Krueger, 2018).

Sensebreaking

Sensebreaking interrupts someone's understanding by different or even contradictory evidence or information provided by others in the process of sensemaking (Pratt, 2000). By means of sensebreaking, stakeholders and other parties can provide negative or critical feedback to an individual (Kaffka et al, 2021). Sensebreaking can take the form of questioning one's existing understandings, redirecting which relates to diverging *"attention […] for solutions"*, or reframing which challenges existing assumptions "of previously held conceptions" (Vlaar et al., 2008: 241). Sensebreaking contributes to reducing equivocality by providing interruption to currently held notions, namely 'atypical cues' in the form of negative or critical feedback.

Conceptual framework

To answer our initial research question of the role of CBL in facilitating the development of adaptive performance among engineering students, we drew on the concepts of socially situated sensemaking mechanisms. To systematise the analysis further, we also used the educational design elements for structured visualisation of results (see Table 1, p.108).

Methods

To analyse how CBL provides exercise in the three mechanisms sense-giving, sensedemanding, and sensebreaking, we study educational design elements in CBL in an empirical context.

Research design

A qualitative research design facilitates exploratory analysis of (shared) meaning-making processes, i.e. use of socially situated sensemaking mechanisms by students during CBL. The study took place at a technical university located in a medium-sized Dutch town. We approached teachers of an (elective) CBL-based course in an engineering graduate programme of that university and obtained permission to carry out research on this course. The course had 25 participants. Most students were graduate students from tracks of computer science, data science and artificial intelligence, and embedded systems. The course was mandatory for students in a specific master-level programme, followed by students from the tracks mentioned. As it was open to master's students from other faculties of the university, there was a small number of students graduating in the fields of industrial design, biomedical engineering, and chemical engineering.

Data collection

Data collection was part of a larger postdoctoral research project carried out by the first author on cognitive factors in students' expertise development in higher education. Data collection included real-time observations as well as retrospective data from interviews with the teaching staff. Permission of an ethical committee for this study was sought and received.

The real-time observational data collection took place by means of field observations carried out by the principal investigator, in following two student teams (each team consisting of five students). The field observations of student teams focused on students' use of sensegiving, sensedemanding, and sensebreaking during solving the challenge, i.e. under conditions of uncertainty and novelty.

In addition, we collected data in the form of two interviews with the teaching staff, using open-ended questions. The interviews with the teaching staff helped to get a better understanding of the vision behind educational design of CBL used in this course. Recently, scholars (Van den Beemt et al., 2023) have argued that vision as an essential element of CBL design. The interviews were used to provide insights into the vision, i.e. aims and objectives, of the course, with data recorded and transcribed.

Data coding and analysis

The central analytical concepts of this study are sensedemanding, sensebreaking and sense-giving. Using content analysis, we carried out first-level coding by identifying data containing reference to the three socially situated sensemaking mechanisms of sensegiving, sensedemanding, and sensebreaking. The distinctive empirical qualities of these three concepts facilitated their empirical analysis. Also,

prior research has operationalised the central concepts (sensebreaking, sensegiving and sensedemanding) into empirical indicators which have been validated in empirical research (Kaffka et al., 2021).

A codebook was used to identify relevant discourse of students for analysis. Table 1 contains the codebook. It translates the central analytical concepts of sensegiving, sensedemanding and sensebreaking into empirical indicators to allow for a transparent coding process during the analysis and to ensure the validity and reliability of the findings. The codebook does so with signal words, which helped to reliably identify and categorise entrepreneurs' discourse from the interviews.

In first-order coding, discourse transcribed from the observations was coded into (one or several) of the sensemaking-related mechanisms: sensedemanding, sensebreaking, and sensegiving. It must be noted that just as the latter can occur in association with either of the former three, the three mechanisms can also appear intertwined with each other in respondents' discourse.

In second-level coding, data were categorised according to the relationship with context, curriculum, and task-related factors of educational design. Researcher triangulation, coding of the data by different researchers, was used to ensure interrater reliability.

Findings

Table 1 (p.108) displays the key findings of the analysis. They are presented in more detail below, in terms of context-, curriculum-, and task-related factors of educational design of CBL.

Context design

The course takes place in a centrally located venue on the campus. In the same building yet another part the university hosts its 3D printers and some other larger equipment for prototyping. The course room has an open floor plan and consists of a large, high-ceiling, open space setting on the first floor of a two-story campus building. The area designated as teaching space for this course was equipped with square, sturdy and spacious worktables. The long side of the course floor space was formed by high windows. There were many electricity outlets at the worktables (hanging from the ceiling) and there were a few work benches (equipped with drilling etc. facilities) at the lower end of the course space.

There was no mandatory presence. Neither was there a door to enter the location of the course, or walls surrounding it, as the course space was part of an open floor plan of the entire building's floor, except for a few meeting rooms in the middle of the vast space. Instead, mid-raise high shelves formed boundaries to different groups who occupied the space. In addition to the students' course space, which covered one entire half of the building's floor plan, there were office desks and meeting rooms as well as an open space area with several tables and a general helpdesk (for office

TABLE 1 CONCEPTUAL FRAMEWORK DEPICTING SOCIALLY SITUATED SENSEMAKING MECHANISMS (RELEVANT FOR ADAPTIVE PERFORMANCE) OBSERVED IN CBL

Sensemaking-related mechanisms	Challenge-based learning educational design elements		
	Context	**Curriculum**	**Task**
Sensegiving	■ Socially and physically safe environment for collaborative discourse	■ Use active learning activities ■ Presentation of abstract materials early in the training ■ Facilitate integration of conceptual ideas with existing knowledge ■ Meaningful variation around conceptual or procedural knowledge (emphasising understanding)	■ (Increasing) task variability and complexity (case-proficiency scaling) ■ Reflection and flexibility-focused feedback ■ Guided discovery
Sensedemanding	■ Exploration	■ Exploration ■ Hypothesis testing	■ Exploration ■ Hypothesis testing ■ Using questions
Sensebreaking	■ Encourages productive failure	■ Inclusion of opportunities for struggle, risk-taking, and failure ■ Creating a positive error condition	■ Positive error condition ■ Using framing errors as guideposts

materials, print paper, etc.). The open floor plan of the building made it impossible to have visual control of students. But this did not appear to worry the teachers. In the interviews, the teaching staff confirmed this observation. They reported that their students were expected to come in on Wednesday between 1 and 3 pm to work on their challenge, but there was no timekeeping of any kind, and they had no intention of refusing students from wandering in and out of the area in which the teachers were seated.

All worktables were designed to sit at least four to six people. There was no teacher's desk for the teaching staff. It made the educational staff literally equal to students, in the sense of belonging to the room. Material resources could be accessed easily (and used readily) in the form of small electronic and construction tools and related equipment, which were within hand reach. Also, students were allowed to get hot beverages with the teacher's coffee card, which contributed to the teacher-student bond, or freely grab various materials and instruments.

By demonstrating accessibility and benevolence (the available equipment and free coffee) in an informal, high-trust context (i.e. no formal attendance taking), teachers instilled trust in students and created the basis for engaging in reflective dialogue with them. Such an informal context facilitates collaborative discourse, which is known to develop adaptive performance among students (Kua et al., 2021).

We observed that the more time teams spent in the course area, the more they used various materials and equipment present (cutting and drilling tools). They not only used these tools to express their ideas to each other, engage in feedback, or in shared novel meaning-making processes. They also played with materials or would simply throw ball-shaped objects to each other.

For student teams which sought to tackle (the complexities of) their challenge, the context provided literally and figuratively space for experimental try-outs, debates, disagreement, and failure. In this way, students were embedded in a context which explicitly treated errors as positive ('error-friendly'). In that way, the physical and social context of CBL provided students with a safe environment offering opportunities for and enabling (productive) failures – and learning – in a condition where it was safe to struggle, take risks, and fail. We observed that this stimulated students' explorative activities.

We observed a 'positive error condition' in CBL, which provided students with opportunities to exercise their sensegiving, sensedemanding, and sensebreaking skills. This occurred during deliberation about ideas, design and testing of an idea, or using a certain tool or mechanism to make a prototype. The communication involved required students to use the three socially situated sensemaking mechanisms (with their team members, their peers, the teaching staff, or the challenge-owner), constituting so-called collaborative discourse conducive to the development of adaptive performance (Kua et al., 2021). Collaborative discourse describes student-centred discourse which elicits students' engagement and reflection by means of questions (Bowers et al., 2020).

Our findings show how the context of CBL educational design provides a stimulating and resource-rich context for exploration and failure for students. This context offered students opportunities to not only engage in sensegiving, but also in sensedemanding and sensebreaking, during performance adaptation.

Curriculum Design

The course followed phases typical for CBL: 1) identification of a challenge, 2) generation of ideas, 3) consideration of multiple perspectives, 4) research and revision, 5) testing, and 6) going public. This corresponds closely with active learning approaches which are used for development of adaptive performance in higher education (Gallagher & Savage, 2023). The teaching staff acted mainly as mentors for the students, treating the students in a very informal, open way. In addition, we observed that there was one student assistant. The latter was himself a student about to graduate from the same university.

During the different phases of this CBL course, the teacher-student interaction followed a guided discovery process. Guided discovery describes that supportive information occurs in the form of feedback as well as reflection on how things are organised and how tasks are best approached (Bohle, Carbonell, & Van Merriënboer, 2019). This CBL course integrated summative with formative assessment, the latter consisting of regular feedback and reflection moments aimed at supporting students in their learning tasks.

We noted a very informal relationship between teaching staff and students (mentorship). For example, students were allowed to grab coffee (using the teacher's coffee card). The two teachers who co-taught this course – one with substantial prior industrial experience – encouraged exploration and experimentation by students. In the interviews, teaching staff explicitly emphasised the importance of (stimulating) students' feedback-seeking and processing.

During the first weeks of the course, the learning task of students was to understand their challenge – from other perspectives. During the course, student teams made noticeable use of the teachers' and student assistants' knowledge and support. This occurred very informally during the course. Occasionally, an alumni of the course would also drop by to give teams informal feedback on the teams' definition and solving their challenge.

The learning environment created by the curriculum extended the safe learning environment created by the context by emphasising autonomy, exploration, and room for struggle and failure. Guided discovery and engagement in feedback encouraged critical reflection along students' use of sensedemanding in exploration of the challenge including seeking other perspectives.

We give an example. A situation was observed in which a student signalled to the teacher that his team was stuck with the development of a solution for the challenge. The student expressed his inability to identify the right solution that his team should pursue.

> *Student: "We don't know what sensors work.."*
> *Teacher: "..I agree with that. And that is why I said you need to work closely with the problem owner. To know exactly what they need. And also, to know how they look at it and use it."*

We observed that this teacher invited the student to seek other perspectives, by encouraging him to find out from i.e. engage in sensedemanding with the challenge-owner, regarding the challenge-owner's perspective on the (potential) solution currently ideated by the student team. The communication between teacher and student illustrates how the teacher sought to engage the student in reflection on how to achieve the task and why.

We know from research that reflection on task performance builds conceptual knowledge (Ward et al., 2018). We observed that the teacher used the framing error of the student as a guidepost, as he redirected the students' attention from domain-related expertise (knowing the workings of sensors) to the importance of customer orientation (seeking information from the challenge-owner) to achieve the task. The instructional methods used in this situation - guided discovery, using framing errors as guideposts, and seeking to teach cognitive strategies to support students' learning - have all been associated with building adaptive performance among students (Bohle Carbonell et al., 2014).

Task design

In this course, student teams were connected to a challenge owner (a business or organisation) who presented an open learning task. This was in the form of a challenge in the field of applied technology. With (consideration of) the challenge-owner, the student teams identified a concrete problem related to the challenge. Then, always taking the challenge-owner's perspective, the teams must ideate a technology-based solution for (parts of) the challenge, design a technology serving to implement the solution (in the form of a working prototype), and identify a product/market fit for it.

Tasks in this CBL-based course had a high variability, as achievement depended on iterative co-creation with a challenge-owner and possibly other relevant stakeholders, through interaction. We observed that students had to incorporate an increasing amount of 'details' into solving of the challenge. In that way, students' tasks also showed a high degree of coordinative and dynamic complexity.

The ambiguity of the challenge and potential solutions associated with this challenge played a role, as well as considering the (differing) perspectives of each team member on the tasks to be performed. The inherently ambiguous tasks required students to use various skills associated with adaptive performance, managing expectations of and relationships with others (i.e. with team members, challenge-owner, or teaching staff) in task achievement. As teams were interdisciplinary teams, they had to communicate and negotiate with each other about the understanding and carrying out of activities involved in task achievement.

We give an example. In one situation, students were under time pressure

to finish their task (a mid-term presentation). Two team members were working on the same presentation in the same file simultaneously. Both were visibly stressed and busy finishing a PowerPoint presentation, which was due to be presented by them in a few minutes. The two students were evidently not agreeing on the layout of the slides. They were looking down on their respective screens from opposite sides of the table, intent and time-pressed to finish the task at hand. They did so by asking questions about each other's changes in layout (sensedemanding), by rebutting the other's change verbally (sensebreaking), and trying to establish shared meaning by means of persuasive rhetoric and humour, seeking to reconcile their different perspectives about a specific layout of a slide (sensegiving). This made for frequent, sped-up use sensegiving, sensedemanding, and sensebreaking, which aided the students to achieve the task in time.

We observed that fast, frequent, and simultaneous use of sensegiving, sensedemanding, and sensebreaking facilitated students' achieving the task at hand, namely finishing the PowerPoint presentation in time for the presentation. In a process of a few minutes, the two students managed to articulate, signal, analyse, and reconcile their differences, reaching consensus on the design of each slide, and finishing with the layout of it just in time.

Two main findings emerged from the analysis which help answer our initial research question. One, the educational design of CBL contributes to the development of adaptive performance by exercising relevant sensemaking skills. Notably, high frequency of socially situated sensemaking mechanisms helped students to adapt their performance to achieve the task. Two, the three socially situated sensemaking mechanisms help explain how educational design elements of CBL facilitate the provision of indicators for empirical assessment of adaptive performance (development) among students in higher (engineering) education.

A sensemaking perspective on adaptive performance development in CBL

The physical setting of the CBL course, namely in a prototyping facility, offered an abundance of resources to ideate and prototype. Also, the teachers guided students informally through the course, making the latter noticeably feel at ease and free to experiment. We found that this educational context affected students' communicative engagement.

Our findings confirm prior research, namely that a safe environment is a key condition for development of adaptive performance in higher education, by having a general effect on preparedness to innovate and be creative (Kua et al., 2021; Gube & Lajoe, 2020). A study by Kuismin et al. (2024) showed that discursive and affective reconfiguration of space aids the enactment of ambiguity in task achievement under conditions of uncertainty and novelty.

And so-called 'in-between spaces' facilitate organisational and professional learning (Bailey, Winchester, and Ellies 2023). Such spaces are characterised by an informal, open environment which enables the fusion of technology and work in organisations (Orlikowski & Scott, 2008). The physical and social setting of CBL education, i.e. the resources which students could

literally play with and the informality of the teaching staff, represent an 'in-between' space and helps to explains how students' learning is enabled.

Our findings provide an account of the micro-level mechanisms which enable collaborative discourse, namely: sensegiving, sensedemanding, and sensebreaking. Used together, these socially situated sensemaking mechanisms exercise students in collaborative discourse. While sense-giving aims at creating shared understanding, both sensedemanding and sensebreaking constitute more inquisitive and critical cognitive processes (Kaffka & Krueger, 2018; Kaffka et al., 2021; Kaffka et al., 2024).

Sensebreaking played an important role in collaborative discourse of students because it helps them to identify (and subsequently address) differing and contradictory perspectives or information. Recognising so-called 'atypical signals', or cues from the environment, is essential in adaptive performance of professionals (Klein et al., 2007).

Sensedemanding manifested in teaching staff asking questions and seeking new or alternative information. We observed that open questions by teaching staff helped to 'grease' the feedback for students. This corroborates research which underlines the role that use of questions plays in developing adaptive performance in higher education (Charbonnier & Voirin, & Roussel, 2012).

It has been argued that "students need a knowledge of the meta-linguistic features of argumentation (claims, reasons, evidence, and counterargument) to identify the essential elements of their own and others' arguments" (Osborne, 2010: p. 466). We observed that collaborative discourse, and in particular (negative) feedback loops in which students used sensedemanding and sensebreaking, provided students with exercise in challenging claims, using counter-argumentation, and perspective-taking.

This exercise in using socially situated sensemaking mechanisms practised sensemaking skills of students essential in collaborative discourse (Kua et al., 2021) and which contributes to the development of adaptive performance among students (Fisher & Peterson, 2001).

Assessing adaptive performance development

In this study, we explored the role of socially situated sensemaking mechanisms associated with collaborative discourse. We found that CBL offers ample exercise in sensemaking mechanisms. The three mechanisms are empirically distinctive phenomena, hence representing quantifiable indicators for assessment of collaborative discourse in higher education.

The three mechanisms also have not yet been recognised for their value in assessing (meta)cognitive development of engineering students, although such development supports that of adaptive performance among professionals (Kaffka et al., 2024). Specifically, integration of sense-breaking is an important enabler of developing adaptive performance.

We see that CBL echoes this in context, curriculum, and task-related elements in the form of a positive error condition and incorporating struggle.

Extant works suggest that CBL might encourage building adaptive performance by enabling students to learn via so-called collaborative discourse (Kua et al., 2021). Collaborative discourse describes student-centred discourse which elicits students' engagement and reflection through questions (Bowers et al., 2020).

We know that practising a skill contributes to its development. Along these lines, we argue that students' use of sensebreaking and sensedemanding during collaborative discourse - yields practice in sensemaking skills relevant for adaptive performance. This offers an explanation of how CBL enables collaborative discourse and the development of adaptive performance among engineering students.

Practical implications

Results of our study show that students who practice sensemaking skills during engagement in complex and novel task performance build adaptive performance. The three socially situated sensemaking mechanisms offer empirically grounded indicators for students' pro-active, intentional engagement in collaborative discourse aimed at task achievement under conditions of novelty or uncertainty. Hence, we posit that the assessment of when, how, and why students use the three sensemaking-related mechanisms can help understand differences in adaptive performance as well as how micro-level practices shape the development of adaptive performance.

Assessment of students' use of sensegiving, sensedemanding and sensebreaking – in their proper teams, with their peers, the teaching staff, or the challenge-owner - can help gauge the development of adaptive performance-related cognition, among higher education students as well as in continuing education. Inarguably, to be effective such a learning environment must be a safe setting, i.e. socially and physically functional and protective.

As shown in extant work, a safe environment contributes to building adaptive performance (Kua et al., 2021). We propose that students' engagement in sensedemanding and sensebreaking, i.e. negative feedback loops can be indicative of the way students perceive their learning environment. Extant work shows that sensedemanding and sensebreaking are indispensable in adaptive performance development of professionals (Kaffka et al., 2024) as well as in the development of entrepreneurial ventures (Kaffka & Krueger, 2018).

We suggest that educational interventions aimed at adaptive performance development should stimulate and monitor students' use of questions (more) as well as their engagement with (negative) feedback within and outside the classroom, such as with a challenge-owner or relevant stakeholders.

Training in socially situated sensemaking mechanisms goes beyond higher education. Today's managers seek to make their organisations more flexible and responsive (Mergel, Ganapati & Whitford, 2021). Intentional use of them can help professionals become more adaptive at work (Kaffka et al., 2024). We suggest their training contributes to building young engineering professionals' sensemaking skills relevant for adaptive performance. In that sense, skilled use of these socially situated sensemaking mechanisms presents a valuable lifelong learning asset.

Conclusion

This study showed that in addition to curriculum- and task-related elements, context-related factors of CBL design are crucial for exercising students' sensemaking processes relevant for development of their adaptive performance. We propose that sensegiving, sensedemanding, and sensebreaking clarify conceptually how social interactive context matters in adaptive performance and its development. Also, these three concepts represent analytical tools suitable for empirical research on adaptive performance and its development in higher education.

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8 | Exploring adaptive performance of health professions educators with the D-ADAPT-HP

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8 | Exploring adaptive performance of health professions educators with the D-ADAPT-HP

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ABSTRACT **Today's rapidly changing world and complex challenges requires flexibility and adaptability from our professionals. Adaptive performance is relevant for professionals in all kinds of domains, such as engineering, health professions, the military, and education. To study the perceived need for adaptive performance the D-ADAPT questionnaire can be used.**

This questionnaire is developed with military professionals in mind. In this book chapter, we describe our efforts to adapt the D-ADAPT questionnaire for use in Health Professions (HP) Education, resulting in the D-ADAPT-HP.

We delineate the steps taken in this process: reformulated some questions, conducted confirmatory factor analysis to study its' suitability for use in HP Education. In addition, we analysed differences in the perceived need for adaptive performance for HP educators' job as a whole and for those who combine tasks areas in their job (i.e., teaching, research, and patient care).

Based on our results we investigated differences between military and HPE and identified the actions to be taken to use D-ADAPT in other contexts like engineering.

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Introduction

Today's rapidly changing world and complex challenges requires flexibility and adaptability from our professionals (Myloupolos et al., 2018; Pelgrim et al., 2023). There is an increase in studies conducted to get insight in the elements of adaptive performance that professionals in a certain domain need. For example, Oprins et al. (2018) studied adaptive performance in the military context, and Bus et al. (2022) studied adaptive performance of hospital employees during the COVID-19 pandemic. Adaptive performance is relevant for professionals in all kinds of domains, such as professional development for adaptive performance in engineering and education (Martin et al., 2015; Van Tartwijk et al., 2017).

Utrecht University aims to support students to develop adaptive expertise and become adaptive performers, as stated in 'The New Utrecht School' vision (Van Geelen & Milota, 2022; Van der Schaaf, 2022). Yet, we do not know to what extend our own educators in the university hospital are adaptive experts and adaptive performers themselves. To gain insight in their level of adaptive expertise, we studied which types of adaptive performance our health professions (HP) educators recognise and deem important for their own work, especially when combining different tasks (i.e., teaching, research, and/or clinical work). In this chapter, we describe how we adjusted and applied the Dutch Adaptability Dimensions And Performance Test (D-ADAPT; Oprins et al., 2018) to the context of HP education. The D-ADAPT questionnaire is used to measure professionals' perceptions about the level of adaptive performance that is needed in their job. It is also possible to measure how professionals perceive their own level of adaptive performance. However, the focus of this chapter is on the former. We address the literature on adaptive expertise and adaptive performance, how we applied the D-ADAPT questionnaire for use in a health professions education context, and our efforts to validate this questionnaire for this professional domain. Insights based on this study could be used to apply the D-ADAPT questionnaire to other professional domains, such as engineering.

Adaptive expertise and adaptive performance

To develop expertise in task performance, one needs to develop routines, by deliberately practicing the (part-)tasks involved (Ericsson, 2008), because practice and routines lead to efficiency in task performance (Hatano & Inagaki, 1986). However, this does not necessarily mean that someone who is an expert always performs better than a novice or intermediate expert in all situations. Especially when professionals primarily rely on routines they may perform poorly in new or unexpected situations, because they are unable to adapt. According to Van Tartwijk et al. (2017), relying on routines can be risky, especially when environmental or task factors are prone to change.

Already in 1986, Hatano and Inagaki made a distinction between *routine expertise* and *adaptive expertise*. This distinction has gained more attention in the past decade. The term adaptive expertise is referred to as being able to adapt to new or unexpected situations, which requires creativity, flexibility, problem-solving skills and deep conceptual knowledge about the nature of the task (Bohle-Carbonell et al., 2014; Hatano & Inagaki, 1986). Elaborated conceptual knowledge helps an expert to think beyond routines and generate innovative solutions adapted to what the specific situation calls for.

Many definitions of adaptive expertise and performance can be found in the literature. In this chapter we adopt for adaptive expertise the recently proposed definition of Fluit et al. (2024), which states it concerns the ability to identify new, unexpected and complex situations that demand new ways of acting, yet unknown to the professional, as well as the ability to act accordingly in such situations. We distinguish adaptive expertise from adaptive performance as the counterpart of adaptive expertise that is observable in behaviour. We define adaptive performance therefore as observable behaviours that represent adaptive expertise (Fluit et al. 2024).

Pulakos et al. (2000) identified eight aspects[1] of adaptability as a taxonomy for adaptive (job) performance. These aspects were later used as the basis for the I-ADAPT theory by Ployhart and Bliese (2006). These eight aspects of adaptability are: (1) *Handling emergencies or crisis situations,* (2) *Handling work stress,* (3) *Solving problems creatively,* (4) *Dealing with uncertain and unpredictable work situations,* (5) *Learning work tasks, technologies, and procedures,* (6) *Demonstrating interpersonal adaptability,* (7) *Demonstrating cultural adaptability,* and (8) *Demonstrating physically oriented adaptability.*

Short descriptions of the adaptability aspects are provided in Table 1 (p122). Both Pulakos et al., (2000) and Ployhart and Bliese (2006) developed their own questionnaire to measure adaptive performance of professionals in complex environments; These are called the Job Adaptability Inventory (JAI) and the individual adaptability measure (I-ADAPT-M), respectively.

Dutch Adaptability Dimensions and Performance Test

To measure the self-assessed needs for adaptive expertise to properly function as a professional, as well as to measure the self-assessed level of adaptive expertise of military professionals, Oprins et al. (2018) developed the Dutch Adaptability Dimensions and Performance Test (D-ADAPT). The D-ADAPT is a revised combination of the Individual Adaptability Measure (I-ADAPT-M; Ployhart & Bliese, 2006) and the Job Adaptability Inventory

1 Pulakos et al. (2000) refer to these aspects of adaptability as dimensions. As dimensions are statistically difficult to identify, we chose to refer to these dimensions as aspects of adaptability throughout this chapter.

TABLE 1 TAXONOMY AND DESCRIPTIONS OF ADAPTABILITY ASPECTS [ADAPTED FROM PULAKOS ET AL., 2000)].

ADAPTABILITY ASPECT	DEFINITION
Handling emergencies or crisis situations	Involves making (split-second) decisions in response to a life-threatening or dangerous situation, or an emergency, while remaining calm and focused.
Handling work stress	Involves remaining calm and cool while handling difficult situations and a highly demanding workload.
Solving problems creatively	Involves applying unique and innovative solutions to problems and thinking outside of the box, by involving seemingly unrelated information or looking at a wide range of possibilities.
Dealing with uncertain and unpredictable work situations	Involves taking action in situations that are unclear, unexpected, in situations where a total picture or information is missing and therefore might be unpredictable.
Learning work tasks, technologies, and procedures	Involves enthusiasm and action to continuously develop to keep knowledge and skills current. This may involve learning about new technology or procedures.
Demonstrating interpersonal adaptability	Involves keeping an open mind in interaction with others, careful listening, and considering other's viewpoints.
Demonstrating cultural adaptability	Involves openness to learn about values and customs of other cultures, and the willingness to adjust behaviour accordingly, when necessary.
Demonstrating physically oriented adaptability	Involves adjusting to challenging environmental states (e.g., extreme heat or dirtiness) by pushing oneself physically to complete the necessary task.

(JAI; Pulakos et al., 2000) (Oprins et al., 2018). Originally, the D-ADAPT consisted of the eight aspects of adaptability as proposed by Pulakos et al. (2000). However, during validation, results showed that two of the aspects (i.e., 'Dealing with uncertain or unpredictable work situations' and 'Learning new tasks, technologies, and procedures') showed a bad fit for use in the military population. These aspects were therefore eliminated from the questionnaire. The final version of the D-ADAPT measures six aspects of adaptive performance using 31 items: (1) Handling crisis situations (HCS), (2) Solving difficult problems (SDP), (3) Culturally demanding situations (CDS), (4) Physically demanding circumstances (PDC), (5) Handling work stress (HWS), and (6) Interpersonal interaction (II).

The D-ADAPT can be used in two versions. Note that the items for both versions are the same, only the stem is different. The first version is called the *work-adapt* and can be used to assess professionals' perceptions of the amount of adaptive performance their job requires. The guiding question in this version is "How important do you consider this behaviour for your work?" Respondents then rate the importance of the behaviours for their job on a 5-point Likert Scale (1 = 'Not important' to 5 = 'Very important'). For example, "How important do you consider this behaviour for your work as an engineer: Adapting your plan to solve a problem". The engineers then rate the importance of the behaviour "adapting your plan to solve a problem". In that sense, the work adapt is used to study the necessary behaviours or even competencies for adaptive job performance.

The second version is called the *self-adapt* and can be used to measure respondents' perceptions of their own level of adaptive performance. The guiding question here is "How effective do you consider yourself at performing this behaviours in your work?" In that case respondents rate their competency in terms of their effectiveness on a 5-point Likert Scale (1 = 'Not effective' to 5 = 'Very effective'). For example, "How effective do you consider yourself at performing this behaviour in your work as an engineer: Adapting your plan to solve a problem". The engineers then rate how effective they deem themselves in showing the behaviour "adapting your plan to solve a problem". In that sense, the self-adapt measures professional's self-efficacy in adaptive performance.

We selected the D-ADAPT for our study based on a review study and an analysis of the quality of measurement instruments assessing adaptive expertise and adaptive performance (Hissink et al. 2025). This instrument demonstrates adequate validity, reliability, and fairness in its testing. It is suitable for use with professionals and is also applicable to the target group of future professionals, i.e. students (Hissink et al., under review).

Changes made for use in health professions education

When used in a new context it is important to consider whether the measuring instrument will be fit and valid for that new context (Kane, 2013). The original D-ADAPT was developed to measure adaptive performance of military personnel. Some of the items include military terminology, which may not resonate with professionals from other domains, such as HP educators, the target group of our study.

We therefore made some minor adjustments to the formulation of some items so that the content would fit the target group of HP educators better. As we made some changes to the formulation of items we refer to our version of the D-ADAPT as D-ADAPT for Health Professions (D-ADAPT-HP). These adjustments are the same for both the *work-adapt* and the *self-adapt*, so that both versions can be used. Adjustments to the formulations were mainly made for the items measuring HCS.

For example, instead of using 'crisis situation' (D-ADAPT question CRS1) and 'emergency situation' (D-ADAPT question CRS2), we used the term 'unexpected situation' in both items, HCS6 and HCS7 in the D-ADAPT-HP (see Appendix). We chose to make this adaptation also because in the current definition of adaptive expertise the focus mainly lies on being able to perform in unexpected situations (Fluit et al., 2024); these are not necessarily crisis situations or emergencies. We used "…when a situation escalates" instead of "… when a situation turns dangerous" (D-ADAPT question CRS5); and "…when a situation becomes too dangerous" (D-ADAPT question CRS8) and 'worsening' instead of 'threatening' in CRS3, HCS8, HCS9, and HCS10 in the D-ADAPT-HP.

Of course, in specific cases situations can become dangerous, think about violence against ambulance personnel or physical exposure to x-ray or infectious diseases (e.g., COVID-19). Yet, in HP education, situations tend not to become dangerous or threatening for the HP educators themself. Given that our target group was HP educators, we chose to adjust the term dangerous to unexpected.

The present study

Most educators in the Health Professions domain have built a career in patient care before becoming a HP educator (Ten Cate, 2021). A large group of educators still combines their clinical work with teaching, as a second career or secondary or even tertiary job task to clinical and/or research tasks. Teaching is a very complex and demanding task (Cornelius-White, 2007), and HP educators may feel that their teaching activities are undervalued (Van Lankveld et al., 2017). Therefore, in their professional development HP educators may focus more on developing their Health Professions knowledge and skills rather than on developing their teaching skills.

In all their tasks, adaptive performance is essential to the HP-educator. This is reflected in how they feel about the need to be adaptive performers in their *job as a whole*. However, some task areas may require more adaptive performance than others. It is important to explore differences in adaptive performance needed for certain task areas. As HP educators are tasked with stimulating students to develop adaptive performance, they may benefit from insights about the different degrees of adaptive performance needed for different tasks. Further, such insights could provide avenues for specific professional development opportunities for HP educators, as well as for students who are trained to perform these tasks in the future.

Additionally, when a HP educator combines teaching with other medical tasks in his professional job (e.g., patient care and/or research), this sets additional demands on the person's adaptive qualities. It remains unclear

which demands on adaptive performance are being asked from HP educators and whether these differ between task areas. Knowledge on these demands could provide insight in how HP educators could be supported in developing their own adaptive performance.

The goals of the present study were: (1) to test whether an instrument developed for military personnel could be adapted and applied in the domain of HP educators; (2) to get insight into the demands experienced by HP educators in general, for teaching specifically, and per constituent tasks in case their job consisted of multiple task areas (teaching, research, and patient care). This was measured by means of the *work-adapt* version of the D-ADAPT-HP; and (3) to explore whether the need for adaptive performance in HP education differs from the military domain, for which the D-ADAPT was originally developed. To that end, this study could serve as a first external validation attempt of the D-ADAPT, that could also inform adjustments or application of this questionnaire in other domains, such as engineering.

Method

Design and ethical approval

This study followed a quantitative online survey design. Ethical approval for this study was obtained via the Netherlands Association for Medical Education (NVMO) Ethical Review Board application number 2022.6.6. Informed consent was granted by respondents at the landing page of the online administered questionnaire.

Participants and procedure

The target participants were HP educators if they were registered: (1) as requiring the University Teaching Qualification (UTQ), (2) as having started the UTQ trajectory, or (3) as having finished the UTQ trajectory. HP educators were invited to participate in the study via direct email. The questionnaire was administered on-line using Qualtrics.

Instruments

Adaptive performance

Adaptive performance of HP educators was measured using the work-adapt version of the D-ADAPT-HP. The participants were asked to fill out the D-ADAPT-HP up to four times: First, for their *Job as a whole*, and then up to a maximum of three additional times for each of their constituent task areas: *Teaching*, *Research*, and *Patient care*, depending on the task areas they were responsible for or involved in. We did not administer the Self-ADAPT for this study. First, because we made changes to some of the items and wanted to validate the new version of the work-adapt version first. Second, because we wanted to explore our HP educators' perceptions of the need for being adaptive performers. And finally, as we already asked them to fill out de D-ADAPT-HP multiple times, we did not want to make the questionnaire any longer or confuse them with rating the same items even more.

Some participating HP educators are non-native Dutch speakers. We therefore offered participants the choice completing the questionnaire in English

or in Dutch. The D-ADAPT-HP questionnaire consists of 31 items that measure six aspects of adaptive performance. The items were rated on a 5-point Likert scale (1= "not important:" to 5 = "very important"). Example items per aspect were: (1) HCS: *"Monitoring how an emergency situation unfolds in order to adapt your behaviour"*; (2) SDP: *"analysing an unfamiliar problem"*; (3) CDS: *"Adjust your goals to accommodate people from a different culture"*; (4) PDC: *"Recognizing when physical circumstances make your job harder to carry out"*; (5) HWS: "*Determining why you feel stressed"*; and (6) II: *"Taking the possible reactions of other into account"*. For the full original version of the D-ADAPT see Oprins et al. (2018), the English version of the D-ADAPT-HP can be found in Appendix A.

Analysis

The statistical software JASP (version 0.19.0) was used for all analyses. To test whether the factor structure underlying the data corresponded to the six expected aspects, four Confirmatory Factor Analyses were performed (i.e., one per task area: Job as a whole, Teaching, Research, and Patient care). Cronbach's alphas were calculated for the final six subscales of the D-ADAPT-HP.

We conducted six one-sample T-tests to study whether the means for the separate tasks differed from the means for *Job as a whole*. We tested these effects using a Bonferroni corrected alpha level of .004 (i.e., to correct for multiple testing against *Job as a whole* and against *Patient care*).

To test whether the perceived need for Adaptive Performance on each aspect differed for HP educators whose job consists of multiple subtasks, we first created groups of participants based on the tasks for which they completed the D-ADAPT-HP. This resulted in the following task groups: *Teaching only, Teaching and Research, Teaching and Patient Care,* and *Teaching, Research,* and *Patient care*. We conducted six One-way ANOVAs with each D-ADAPT-HP aspect as independent variable and task-group as grouping variable. We tested these effects against a Bonferroni corrected alpha level of .008, to correct for multiple testing.

Finally, to study the differences between the HP educators' ratings of adaptive performance for 'Job as a whole' and for 'Teaching' with the ratings of the military personnel, we conducted 12 independent sample-tests. The effects were tested against a Bonferroni corrected alpha level of .004 to correct for multiple testing. The Means for the military sample were obtained from Oprins et al. (2018; retrieved from p.8, Table 5).

Results

Participants

In total, 119 respondents filled out the questionnaire for their *Job as a whole*. Not all the 119 respondents filled in the questionnaire for the separate task areas: 85 completed the D-ADAPT-HP for *Teaching*, 66 for *Research*, and 38 for *Patient care* (Note that, respondents could fill out the questionnaire multiple times if they had more tasks. Therefore, these numbers cannot be added up).

When looking at the number of D-ADAPT-HP versions completed by the respondents, they could be divided into the following task groups: Teaching only (n=13), Teaching and research (n=34), Teaching and patient care (n=7), and Teaching, research and patient care (n=31); Unfortunately, 34 respondents could not be divided into task groups, because they only filled out the D-ADAPT-HP for *Job as a whole*. These respondents are only included in the analysis for *Job as a whole*.

Quality and reliability of the D-ADAPT-HP

Factor analysis

To test whether the factor structure of the D-ADAPT-HP also distinguished the six aspects of the original D-ADAPT we conducted four Confirmatory Factor Analyses, that is, separate for each task area (Job as a whole, Teaching, Research, and Patient care).

To determine the sample size adequacy, we obtained the Kaiser-Meyer-Olkin Measure of sampling adequacy (KMO). For Job as a whole, Teaching, and Research the sample size was sufficient (all values >.50, respectively), which is sufficient for obtaining a reliable factor structure. For patient care, the number of respondents was small (n=38). The KMO criterion was <.50 for many of the variables.

This is deemed insufficient to obtain a reliable factor structure. Therefore, we will only interpret the factor analysis results for *Job as whole*, *Teaching* and *Research*.

Similar results were found for all three versions. The initial Model fit indices indicated an insufficient model fit for *Job as a whole*, *Research* and *Teaching*: Job as a whole: $\chi 2$ (419) =723,887, p<.001, CFI=.890, RMSEA=.078; Teaching: $\chi 2$ (419) =663,165, p<.001, CFI=.865, RMSEA=.082; Research: $\chi 2$ (419) =630,059, p<.001, CFI=.854, RMSEA=.087. Yet, the factor structure largely corresponded to the original D-ADAPT but three items did not fit the six aspects. The items with the worst fit were: *"To develop new ways for cooperation"* and *"Changing your mind because of other team member's ideas"* of the II aspect. This could be explained by the other items being more about cognitively taking others into account, whereas these two items are more about action and collaboration. The item *"Adopt an unusual solution to a problem"* of the PSD did not fit within this aspect. We choose to remove these items from the analyses.

Removing these three items from the analysis resulted in the following model fit indices for *Job as a whole* $\chi 2$ (335) =575,038, p<.001, CFI=.911, RMSEA=.078, which is good; for *Teaching* this resulted in $\chi 2$ (335) =531,222, p<.001, CFI=.885, RMSEA=.083 and for *Research* $\chi 2$ (335) =508,625, p<.001, CFI=.876, RMSEA=.088. For *Teaching* and for *Research* the model fit indices show an inconclusive pattern, the Chi-square test and the RMSEA show the model fit is sufficient, the CFI shows the model is insufficient. However, since the number of participants for *Teaching*, *Research*, and *Patient care* are substantially lower, we decided to apply the factor structure with sufficient model fit of *Job as a Whole* to these data. This results in a D-ADAPT-HP version that consisted of six sub-scales with 28 items.

Reliability Analysis

Per subscale of the D-ADAPT-HP and per task the reliability was estimated and presented in Table 1. Note that the number of participants is low, the results should be interpreted with caution. The Cronbach's alpha values for all subscales, except Interpersonal Interaction for *Teaching*, showed moderate to very good reliability. For Interpersonal Interaction in teaching the estimated reliability was .66. This is often deemed insufficient, but since it is above .60, we decided to nevertheless use these results and interpret with caution.

D-ADAPT-HP as a whole

Before looking at the individual aspects of the D-ADAPT-HP we conducted a paired sample T-test to study the differences between the entire D-ADAPT-HP versions of *Job as a whole*, *Teaching*, *Research*, and *Patient care*. The Means and Standard Deviations are provided in Table 1 (Total). The results showed that the D-ADAPT-HP for *Job as a Whole* was scored significantly higher compared to *Teaching* (t= 4.255, p<.001, d=.46) and to *Research* (t=5.290, p<.001, d=.65), and the D-ADAPT-HP for Patient care was rated significantly higher than for Teaching (t=-3.050, p=.004, d=-.495) and Research (t=-2.074, p=.047, d=-.373). The effects were small to medium. The difference between D-ADAPT-HP for *Patient care* and for *Job as a whole* was not significant (t= -0.129, p=.898, d=-.021)).

D-ADAPT-HP aspects in different tasks

Table 1 (p.129) shows the means, standard deviations, and one-sample t-test results for the separate D-ADAPT-HP aspects and for the four distinguished tasks. The two most important findings were that SDP was rated significantly lower for *Teaching* and significantly higher for *Research* compared to *Job as a whole*. HCS was rated significantly lower for both *Teaching* and *Research* compared to *Job as a whole*. The results for *patient care* never significantly differed from *Job as a whole*. To explore whether adaptative performance was rated differently for *Patient care* compared to *Teaching* and *Research* we conducted six more one-sample T-test with the means for *Patient care* as the reference. The differences between aspects showed a similar pattern, except for PDC. Respondents rated those significantly higher for *Patient care* than for *Teaching* and *Research*.

D-ADAPT-HP aspects when combining multiple tasks

HP educators were divided into groups based on all the tasks for which they filled out the D-ADAPT-HP. Since some HP educators only filled out the D-ADAPT-HP for *Job as a whole*, those could not be place in either of the task-groups, therefore we proceeded the analysis with the remaining data of 83 HP educators. The results are presented in Table 2 (p.130). With the Bonferroni corrected alpha level, none of the differences were significant.

However, two effects are worthwhile mentioning: the ratings for dealing with CDS and for HCS, which could be interesting for future studies that include more participants combing multiple tasks. It appears that CDS need lower adaptive performance for HP educators who combine *Teaching* with *Patient care* than for HP educators who were in the *Teaching only* or the *Teaching and Research* group. For HCS, the means are pointing towards

TABLE 1 MEANS, STANDARD DEVIATIONS, AND CRONBACH'S ALPHAS FOR THE D-ADAPT-HP SUBSCALES PER TASK

	JOB AS A WHOLE			TEACHING			RESEARCH			PATIENT CARE*		
	M	SD	α	M	SD	α	M	SD	α	M	SD	α
SDP	4.34	0.52	.86	**3.70**	0.74	.84	**4.54**	0.46	.78	4.23	0.92	.95
HCS	4.16	0.59	.86	**3.91**	0.69	.89	**3.84**	0.74	.89	4.20	1.03	.95
CDS	3.51	0.81	.92	3.50	0.81	.92	**3.09**	0.93	.92	3.52	1.08	.96
II	3.96	0.55	.71	3.89	0.60	.66	**3.55**	0.66	.75	3.89	0.89	.91
HWS	3.81	0.70	.91	3.61	0.76	.90	3.64	0.80	.91	3.74	0.95	.94
PDC	2.93	1.21	.97	**2.72**	1.16	.96	**2.70**	1.18	.96	3.19	1.28	.98
TOTAL	3.72	.50	.93	3.54	.60	.93	3.53	.56	.92	3.80	.85	.97

NOTE

SDP-Solving Difficult Problems. HCS-Handling Crisis Situations. CDS-Culturally Demanding Situations. II-Interpersonal Interaction. HWS-Handling Work Stress. PDC-Physically Demanding Circumstances.

Aspects that significantly differ from the *Job as a whole* mean are underlined. Aspects that significantly differ from *Patient Care* are presented in bold type face.

TABLE 2 MEANS, STANDARD DEVIATIONS AND ONE-WAY ANOVA RESULTS FOR THE DIFFERENT TASK GROUPS

	T-O		T-R		T-PC*		T-R-PC		ANOVA		
	M	SD	M	SD	M	SD	M	SD	F (df)	p	η2
SDP	3.85	0.70	3.81	0.63	3.54	0.92	3.57	0.83	.793 (3,79)	.502	.029
HCS	4.00	0.71	4.10	0.59	3.54	0.85	3.75	0.72	2.249 (3.80)	.089	.078
CDS	3.72	0.66	3.62	0.76	2.66	0.90	3.47	0.81	3.330 (3.79)	.024	.112
II	3.91	0.60	4.04	0.64	3.81	0.18	3.72	0.61	1.436 (3,74)	.239	.055
HWS	3.46	0.87	3.66	0.83	3.23	1.08	3.69	0.53	.799 (3,71)	.498	033
PDC	2.53	1.14	2.74	1.10	1.92	0.74	2.95	1.27	1.452 (3,71)	.235	.058

NOTE

*The number of participants in the Teaching and Patient care group is very low, the results should be interpretated carefully.

T-O Teaching only
T-R Teaching and Research
T-PC Teaching and Patient Care
T-R-PC Teaching, Research, and Patient Care

SDP Solving Difficult Problems
HCS Handling Crisis Situations
CDS Culturally Demanding Situations
II Interpersonal Interaction
HWS Handling Work Stress
PDC Physically Demanding Circumstances

TABLE 3 ONE SAMPLE T-TEST RESULTS BETWEEN HP EDUCATOR SAMPLE AND MILITARY SAMPLE

	D-Adapt Aspect	M	Military reference M	t	df	p
Job as a whole	**SDP**	**4.34**	**4.05**	**6.085**	**118**	**<.001**
	HCS	**4.16**	**3.98**	**3.229**	**118**	**.002**
	CDS	3.51	3.54	-.0346	118	.730
	II	3.96	3.82	2.873	118	.005
	HWS	3.81	3.73	0.104	118	.917
	PDC	**2.93**	**3.81**	**-7.933**	**118**	**<.001**
Teaching	**SDP**	**3.70**	**4.05**	**-4.273**	**82**	**<.001**
	HCS	3.91	3.98	-0.904	83	.369
	CDS	3.50	3.54	-0.491	82	.625
	II	3.89	3.82	1.010	77	.316
	HWS	3.61	3.73	-2.198	74	.031
	PDC	**2.72**	**3.81**	**-8.077**	**74**	**<.001**

NOTE

SDP	Solving Difficult Problems	II	Interpersonal Interaction
HCS	Handling Crisis Situations	HWS	Handling Work Stress
CDS	Culturally Demanding Situations	PDC	Physically Demanding Circumstances

higher ratings for the *Teaching only* and *Teaching and Research* groups compared to the *Teaching and Patient care* and *Teaching, research and patient care* groups.

Adaptive performance HP educators vs. the original military sample

Oprins et al. (2018) developed the D-ADAPT for use in the military context. In their study they also compared their result with those of professionals in other civilian professions. It is interesting to explore whether and to which extent the D-ADAPT-HP scores for *Job as a whole* and *Teaching* of HP educators differ from the D-ADAPT scores obtained in the original study with military personnel[2]. The results are presented in Table 3 (p.131).

The results show that the HP educators in our sample perceive the need for adaptive performance differently compared to respondents from the military sample. PDC was rated significantly lower by HP educators for *Job as a whole* and *Teaching* compared to the military. SDP was rated higher by HP educators for *Job as a whole* and lower for *Teaching* compared to the military sample. HCS was rated higher by HP educators for *Job as a whole* compared to the military sample, for *Teaching* this difference was not significant.

2 It should be noted that this was added purely for exploratory purposes, since these target groups are not entirely comparable, and also small differences in the D-ADAPT-HP compared to the D-ADAPT were made.

Discussion

The goals of this study were: (1) To test whether an instrument developed for military personnel could be adapted and applied in the domain of HP educators; (2) To gain insight in how HP educators evaluate the importance of adaptive performance on six adaptivity aspects, for each of their job as a whole, the constituent task areas separately, and for the combined task areas; and (3) to test whether HP educators assess the need for adaptive performance in their work differently than military personnel does.

How adaptive do HP educators need to be?

The results showed that HP educators indeed need to be adaptive performers, but the extent to which they feel they need to be adaptive differs per aspect and per task area. For example, at average adaptive performance for their job as a whole was scored almost equal as adaptive performance to *Patient care*. Lower ratings were given to adaptive performance needed for *Teaching* and *research*. These are average scores per task, implying that not all participants fulfilled all tasks areas, e.g. many of the participants were not involved in patient care. Our findings could possibly be related to the combination of different tasks, which could make the *Job as a whole* more challenging and might increase the perceived need for adaptive performance. It would be interesting to study this further, for example by conducting a qualitative study on how HP educators combine different task areas.

When compared to *Job as a whole*, the ability to solve difficult problems (SDP) was rated as significantly less important for *Teaching* and as

significantly more important for *Research*. This finding is not surprising because when doing research, one is essentially solving a complex problem, and for that adaptive performance is crucial. Yet, one could wonder whether it then still is adaptive performance or whether problem solving is inherent to the job, and therefore has become routine performance? This question could be answered in future research. For example, whether researchers who excel in their academic career develop better adaptive performance, or is adaptive performance a prerequisite to become a good researcher?

When compared to *Job as a whole*, the ability to handle unexpected situations (HCS) was rated as significantly less important for both *Teaching* and *Research*, probably because when combining the task areas requires dealing with tasks that involve a crisis or an unexpected situation more often. When compared to *Job as a whole*, the ability to deal with physically demanding circumstances (PDC) was rated as significantly more important for *Patient care* than for *Teaching* and *Research*. This finding is as expected, since patient care in general entails more physically demanding subtasks (e.g., carrying patients, running around wards, working in bloody surroundings vs. standing or sitting in front of a classroom or at a desk) than teaching or research does.

When looking into the need for adaptive performance when combining multiple task areas, we did not find a lot of differences between the distinguished adaptivity aspects. Only that HP educators who combine *Teaching* with *Patient care* evaluated the ability to be adaptive in culturally demanding situations (CDS) as significantly less important than HP educators in the *Teaching only* group, or in the *Teaching and Research* group. It could be that participants involved in patient care encounter such situations more often and therefore are more trained to solve those, which could result in a lowered perceived need to be adaptive in such situations.

Finally, since the D-ADAPT was developed for the military context, we considered it interesting to compare our present results with the original military sample (retrieved from Oprins et al., 2018). Results showed that HP educators considered some aspects of adaptive performance as more important for their work than respondents of the military sample did. This suggests that the degree to which adaptive performance in certain aspects is considered important differs between jobs and maybe even between tasks within jobs.

When training students and staff to become adaptive performers, it is therefore advised to carefully analyse what the critical aspects of adaptive performance in a specific profession are, and under what conditions these need to be expressed. For example, for military professionals it may be important to be adaptive in culturally demanding situations (CDS) (e.g., when deployed in a mission in foreign and unfamiliar territory). It may also be important for general practitioners when working in disadvantaged communities. In contrast, being adaptive in culturally demanding situations may be less required for engineers that might work in often well-known and more predictive work environments. Based on this analysis, learning goals regarding adaptive expertise development and adaptive performance could be formulated.

For engineering this could start by analysing the tasks that often require adaptive performance within the domain of engineering, such as solving complex problems. Of course, nuance is needed regarding different areas of engineering. After all, the problems that an aerospace engineer, an electrical or civil engineer comes across, may differ in complexity or urgency. One should keep this in mind when designing education in such different domains.

Suitability of D-ADAPT-HP for HP educators and other domains

When the D-ADAPT is used in a new context, in our case HP education, but also other domains, such as engineering, it is important to build an argument that the results and conclusions obtained with the instrument are valid (Kane, 2013). This includes careful consideration of whether the formulation of items fits with the target group an whether reformulation is needed. In our study we reformulated some items before administering the D-ADAPT questionnaire (See Changes made for use in health professions education in the introduction). For example, changes we made in the formulation of the items measuring Handling Crisis Situations, resulted in the dimension measuring Handling Unexpected Situations. After data collection it is important to assess whether the factor structure underlying the instrument remains intact.

After we removed three items, which were not a good fit with measurement of adaptive performance in HP education, this proved indeed the case in our study. Because we chose to use a previously validated questionnaire and conducted several checks on evidence for validity, we are confident that the D-ADAPT-HP was suitable for measuring adaptive performance in HP education. Yet, for use in other domains, such as engineering, we first recommend to carefully check the validity for use in a new context (Kane, 2013).

Limitations and future directions

Our study has several limitations. First, the number of participants that fully completed all demanded versions of the questionnaire was relatively low. For example, there was only a small number of participants that filled out the D-ADAPT-HP for patient care, which means that we probably did not reach a sufficient number of participants who combined teaching with patient care. At least not sufficient to gain a reliable result from the factor analysis (i.e., KMO criterion was low). As a result, the groups based on task areas were in some cases too small to draw valid conclusions from. Also, the participant we did reach could be prone to selection bias, those teachers motivated to help us with the study.

Second, we did not directly measure all tasks participants literally and primarily conduct in their daily work. We had to make inferences about their tasks by the number of times they filled out the D-ADAPT-HP for different tasks. In a future study, we would specifically ask which task they have and which task they see as their primary task. However, the findings still provide relevant insights for future research and practice.

Next, in our study we were interested in which aspects of adaptive performance were perceived as important for their job by HP educators.

We did not ask them to reflect on their own adaptive performance as HP educators. Although we had good reasons for not administering the Self-ADAPT in this study (see method section), in future studies, it would be informative to also administer the Self-ADAPT questionnaire in addition to the D-ADAPT(-HP). This is especially relevant, to gain insight in the discrepancy between what is needed and what the current level of adaptive performance of HP educators is.

Further, we made small adaptations to the original questionnaire, as we re-formulated the words 'crisis' and 'emergency' in the items into 'unexpected'. As this fits with the current definition of Adaptive Performance this in itself is not a limitation. However, this means that the aspect Handling Crisis Situations does now actually measures something different, namely Handling Unexpected Situations. In our manuscript, for the sake of clarity we kept the aspect name Handling Crisis Situations. In future studies we suggest using Handling Unexpected Situations when using the D-ADAPT-HP. Also, this change has implications for the results concerning the comparison with the military sample retrieved from Oprins et al. (2018). These results should therefore be interpreted with care.

We are confident that we were able to use the D-ADAPT successfully in the domain of Health Professions education. A potential shortcoming of the original D-ADAPT (Oprins et al., 2018) is that it excluded two sub-scales of adaptivity, i.e., measuring the aspects 'Dealing with uncertain or unpredictable work situations' and 'Learning new tasks, technologies, and 'procedures'. In the original D-ADAPT these were removed due to bad fit of the data. Yet, the ability to deal with uncertain and unpredictable situations and the ability to learn about new things during professional development are theoretically of central importance when becoming adaptive experts.

Although it may have been opportune to exclude these aspects for practical reasons in the Oprins et al (2018) study, these aspects would potentially have been suitable for inclusion in our present study. As adaptive performance and adaptive expertise may be expressed differently in different contexts, as the results of the comparison of HP educators to military also seem to indicate. Unfortunately, we did not realise this before collecting our data. In future research, it will be interesting to review the relevance of the omitted aspects and investigate the relevance for the professional domain in question.

This may emerge into different versions of the D-ADAPT, with different sets of subscales to be used in different contexts. It should be noted that reinstating the aspect "Dealing with uncertain and unpredictable work situations" will result overlap with the changes made in de HCS aspect in the D-ADAPT-HP. This requires an extensive study within different domains.

Finally, when studying adaptive expertise and adaptive performance in engineering, future research could focus on exploring the need for adaptive expertise in general engineering tasks, and for different types of engineering. This could result in developing an 'engineering version' of the D-ADAPT and comparing the results on the work-adapt across different types of engineering (e.g., aerospace, civil, electrical etc.). To identify

learning goals on adaptive performance could serve an educational purpose by describing the required competencies for an engineer in the workplace.

Conclusion

Adaptive expertise and performance are essential for optimal functioning in a complex changing world. We encourage researchers from different domains, such as engineering and engineering education, to study adaptive performance needed in their job context. The D-ADAPT is a promising instrument for this.

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APPENDIX

THE ITEMS OF THE D-ADAPT-HP AS ADMINISTERED IN THIS STUDY

ADAPTABILITY ASPECT	ITEM	
Solving Difficult Problems	1	Analysing an unfamiliar problem
	2	Considering a complex problem from multiple perspectives
	3	Adapting your plan to solve a problem
	4	Comparing different solutions to a problem
	5	Adopting an unusual solution for a problem*
Handling Crisis Situations	6	Understanding the unexpected situation in order to make a proper decision
	7	Monitoring how an unexpected situation unfolds in order to adapt your behaviour
	8	Thinking about how to solve a worsening situation
	9	Taking action at the right moment when a situation escalates
	10	Setting new priorities when a situation escalates
Culturally Demanding Situations	11	Being open to how people from a different cultural background behave
	12	Inquiring about rules, values and habits of another culture
	13	Using your knowledge of a culture to interpret the behaviour of people
	14	Considering how to behave in an unfamiliar culture
	15	Adjusting your goals to accommodate people from a different culture
Interpersonal Interaction	16	Observing the behaviour of other people in order to get to know themv
	17	Taking the possible reactions of others into account
	18	Developing new ways for cooperation*
	19	Changing your mind through ideas of team members*
	20	Taking the interest of others into account in your decisions
Handling Work Stress	21	Recognizing signs of stress in complicated situations
	22	Determining why you feel stress
	23	Predicting how stress will affect the quality of your work
	24	Thinking about how you can prepare yourself for stress
	25	Choosing between different options for reducing stress
Physically Demanding Situations	26	Acknowledging your limits in physically demanding situations
	27	Thinking about the physical demands when taking up a task
	28	Thinking about how to maintain optimal performance under demanding physical circumstances
	29	Thinking about ways how to persevere under demanding physical circumstances
	30	Adjusting your plan due to expected changes in the physical task environment
	31	Adjusting your plan due to expected changes in the physical task environment

NOTE

*Removed after confirmatory factor analysis

9 | Stimulating adaptive performance through constructively aligned transdisciplinary education and the Peradex assessment approach

Photo: David Beale | Unsplash

9 | Stimulating adaptive performance through constructively aligned transdisciplinary education and the Peradex assessment approach

Y. Baggen [1], F. van Rijnsoever [2], L. de Jongh [3]

ABSTRACT **In this chapter, we present adaptive performance as a learning outcome of transdisciplinary education via which we can educate students who are capable to help solve grand societal challenges. Based on transfer and a scaffolded approach, we present a constructively-aligned model for transdisciplinary education at the bachelor and master level.**

Further, we introduce the performance-based adaptive expertise (Peradex) assessment approach as a valid and reliable formative assessment to monitor students' adaptive expertise development. Adaptive experts can flexibly use their knowledge and skills to respond to new problem situations in creative and innovative ways. Transdisciplinary education – in which students address real, societal issues and co-create innovative solution pathways together with extra-academic stakeholders – opens-up the door towards the design of education in which students are challenged to address societal issues in education and to develop their adaptive expertise.

In such education, students can learn how to navigate uncertainty, empathise with others, and address grand societal challenges in meaningful ways.

At the end of the chapter, we present design considerations with which educators can design transdisciplinary education in such way that students can develop their adaptive expertise and practice adaptive performance. We invite educators to further develop these design considerations and share inspirational practices to inform teaching practice, including the use of the Peradex approach as formative assessment instrument.

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Introduction

Higher education has the responsibility to learn students how to address grand societal challenges (GSCs; Voegtlin et al., 2022). GSCs, such as migration, rethinking proteins, and the transition towards a circular economy are uncertain, complex, and value-laden in nature. These challenges are ill-defined, change over time, and involve different people with different, changing stakes. In higher education we aim to educate students in such way that they are able to navigate the uncertainty inherent in addressing GSCs (Bohm et al., 2025).

Different pedagogical approaches have been introduced in the literature to educate students who are capable to help solve GSCs. Think for instance of community-engaged learning (e.g., Nguyen & Jessen Condry, 2023), challenge-based learning (e.g., Baggen et al., 2024; Van den Beemt et al., 2023), entrepreneurial learning (e.g., Baggen et al., 2022) and change agent pedagogies (Van Rijnsoever et al., 2023). What these approaches have in common, is that they all offer authentic, reflective, collaborative and engaging learning experiences to students. Students learn across disciplinary boundaries (i.e., interdisciplinary learning; Verreijken et al., 2023) and different parts of society (i.e., transdisciplinary learning; McGregor & Volckmann, 2013). In this book chapter, we refer to such approaches as *transdisciplinary education*.

In transdisciplinary education students collaborate across disciplinary and societal boundaries and use new knowledge to realise societal impact (Visscher et al., 2022). Students are challenged to combine different disciplines and perspectives, which encourages them to empathise with others and be sensitive to different problem contexts (Bohm et al., 2024). GSCs are 'wicked problems', which are nearly impossible to solve. This requires that students learn to accept the complexity of reality and approach phenomena from multiple disciplines and perspectives.

Given the open character of transdisciplinary education, it is difficult to capture students' learning in pre-defined learning outcomes (Sluijs et al., 2024), standalone to develop constructively aligned education in which such learning is assessed. In this chapter, we aim to address this challenge and discuss adaptive performance as measurable learning outcome of transdisciplinary education. Adaptive performance is the "visible expression" of adaptive expertise (Pelgrim et al., 2022, p. 1258). Adaptive expertise is the ability to deal with changing situations that develop in new or unusual directions, while building on routine knowledge (Hatano & Iganaki, 1984). It helps individuals to navigate through uncertainty, and to address challenges that are new to them in creative and flexible ways (Bohle Carbonell et al., 2014; Pelgrim et al., 2022; Ward et al., 2018), as adaptive expertise enables them to be efficient and innovative. We argue

that transdisciplinary education is a promising learning environment to facilitate the development of adaptive expertise and the practice of adaptive performance of students in the context of addressing GSCs. The uncertain, complex, yet social nature of transdisciplinary education makes it an interesting environment full of learning opportunities to develop adaptive expertise and demonstrate adaptive performance.

More specifically, we elaborate how transdisciplinary education can facilitate adaptive expertise development based on its two main dimensions (i.e., efficiency and innovativeness) and transfer, which is the extent to which one can use previous learnings in new problem situations (Cheung & Kulasegaram, 2022). Further, we present how adaptive expertise can be measured with a reliable, valid instrument, namely the performance-based adaptive expertise assessment approach, which we call the Peradex.

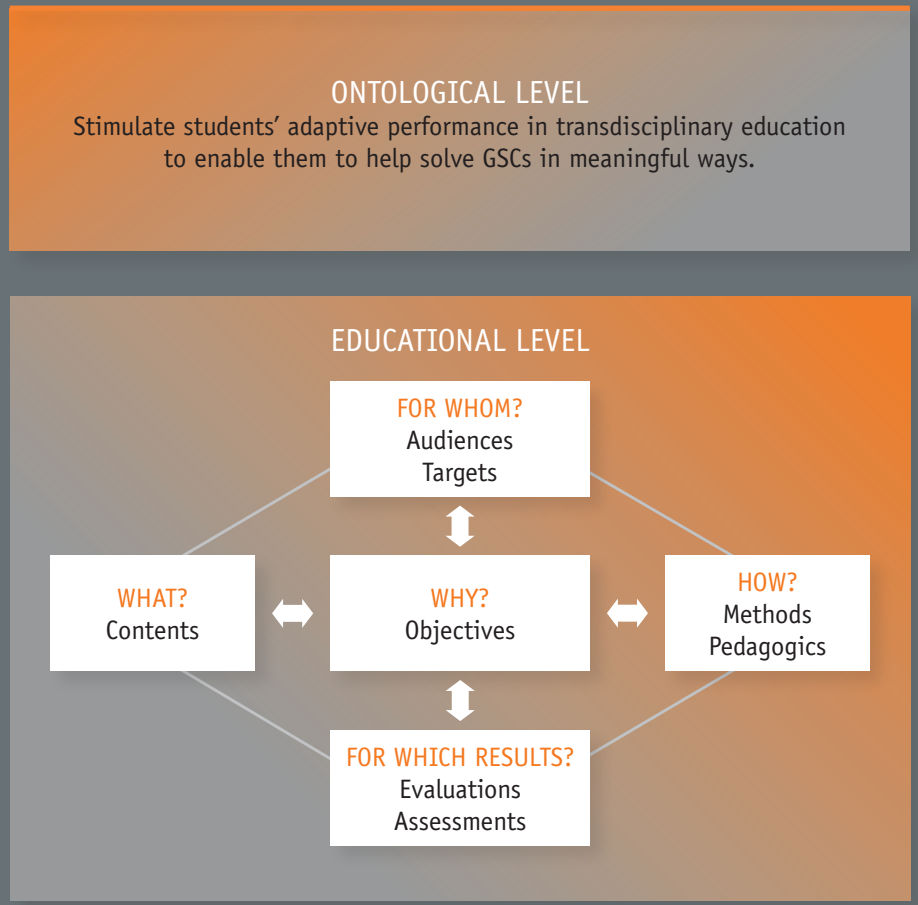
The Peradex consists of design scenarios developed with the help of Artificial Intelligence (AI) and can be used to provide insights into students' performance-based adaptive expertise. The Peradex is available at the edusources website [1]. In the current chapter we share insights on how to use the Peradex in transdisciplinary education, based on a scaffolded approach via which students can gradually develop towards adaptive expertise and start practicing their adaptive performance at the bachelor and master level.

We structure this chapter based on the teaching model framework of Fayolle and Gailly (2008; see Figure 1, p.143). The framework is based on the notion of constructive alignment (Biggs, 1996) and helps to systematically align learning objectives, activities and assessment. Further, the model connects the ontological and educational level. The ontological level captures the underlying aim of education, which is further elaborated in the different dimensions at the educational level. In this chapter, we address each educational-level dimension of the framework. We first conceptualise adaptive expertise and present a model for adaptive expertise development (i.e., *what*), and we translate this to three learning outcomes (i.e., *why*). Next, we discuss how bachelor and master students can gradually develop themselves with regard to the learning outcomes based on a scaffolding structure (i.e., *for whom*). Then, we address how the learning outcomes can be monitored with the Peradex approach (i.e., *for which results*). To conclude, we present design considerations (i.e., *how*) that can be used to create transdisciplinary education as pedagogical approach to stimulate students' adaptive expertise development.

1 Full link: https://edusources.nl/materials/f2663156-3362-4895-a712-a766be7a8c82/adaptive-expertise-assessment

2 In this book chapter, we use disciplines and (knowledge) domains interchangeably.

FIGURE 1 THE TEACHING MODEL FRAMEWORK, ADOPTED FROM FAYOLLE AND GAILLY (2008)



Adaptive expertise and adaptive performance – The What

In this chapter we distinguish adaptive experts from routine experts. Routine experts consistently perform better than others on tasks that are representative for a certain field of expertise. Routine experts have declarative (i.e., knowing-what) and procedural (i.e, knowing-how) knowledge and skills that enable them to solve problems in their domain (Hatano & Inagaki, 1986; Kaffka et al., 2024). They know their domain well and are able to solve problems accurately and quickly (Kaffka et al., 2024).

In contrast with routine experts, adaptive experts are capable of dealing with new problems in their field of expertise in creative and flexible ways (Cheung & Kulasegaram, 2022; Hatano & Inagaki, 1984). Beyond declarative and procedural knowledge and skills, they have conceptual knowledge and skills (i.e., knowing-why). They understand why certain solutions work or not, given a problem situation, and use their conceptual knowledge to "invent" new procedural knowledge (Hatano & Inagaki, 1984, p.30). Adaptive experts also have strong metacognitive skills (Kaffka et al., 2024). Metacognitive skills enable higher level thinking and such 'knowing-why'. Adaptive experts understand principles and relationships underlying a certain domain, which enables them to use their knowledge and skills flexible in novel, non-routine problem situations. They can monitor, regulate, and control their knowledge and skills in such way that they can use their knowledge and skills in new problem situations, and can evaluate thinking processes when working on a task (Akturk & Sahin, 2011).

We define adaptive expertise based on two dimensions: efficiency and innovativeness (Bohle Carbonell et al., 2014). *Efficiency*, also referred to as domain-specific skills, is a basic component of routine expertise. High levels of efficiency help to easily retrieve knowledge to quickly understand and solve a problem (Schwartz, Bransford, & Sears, 2005). *Innovativeness* differentiates adaptive experts from routine experts. Adaptive experts draw analogies to new situations and use their knowledge – decomposed in different building blocks – in new situations. Their metacognitive skills and flexibility helps them to address new problem situations.

The visual expression of adaptive expertise is referred to as adaptive performance (Pelgrim et al., 2022) and is triggered in situations that are characterized by newness – new to the individual or new to the world. We aim to deepen our understanding of how transdisciplinary education can stimulate adaptive expertise development of students and provide opportunities to practice adaptive performance in education.

Near and far transfer

In understanding how students can develop adaptive expertise, transfer is a useful perspective. *Transfer* refers to the extent to which people can use previous learnings in new contexts (e.g., Cheung & Kulasegaram, 2022; Schwartz, Chase & Bransford, 2012). From a cognitive perspective, transfer is perceived as a way to use previously acquired knowledge to new problem situations (i.e., "see the old in the new"; p.1297, Cheung & Kulasegaram, 2022). From a social cognitive and constructivist perspective on transfer, the use of previously acquired knowledge in the process towards the

development of new knowledge is more carefully considered, i.e., "see the new in the old" (Cheung & Kulasegaram, 2022, p. 1302). More specifically, in social cognitive theory, transfer is understood as a cognitive process that takes place in a certain social context (Fulton, van der Schaaf, & O'Brien, 2023). Connections and interactions with others – which are key in transdisciplinary education – play an important role in transfer. We define transfer in line with this approach and perceive transfer as a way to explain how adaptive experts are sensitive to "contextual variation" (Schwartz et al., 2012): adaptive experts are capable of understanding what previously acquired knowledge, experiences and skills are useful to address problem situations in new contexts, and at the same time they are capable of understanding how to be flexible, adaptive and creative given the social context and newness of the problem.

Cheung and Kulasegaram (2022) make a distinction between near transfer and far transfer. *Near transfer* relates to problem-solving in similar contexts. *Far transfer* relates to problem-solving in contexts that are further away from the individuals' disciplinary background or knowledge domain[2]. Near and far transfer are personalized, i.e. a task that requires far transfer for a novice (e.g. a student), may require near transfer for an expert. We focus in this chapter on students who perceive tasks differently compared to professionals who can rely on rich working experience. With this notion in mind, we present a model for first steps in adaptive expertise development.

Model for adaptive expertise development

Building on the two main dimensions of adaptive expertise (i.e., efficiency and innovativeness) and near and far transfer, we propose a model for adaptive expertise development (see Figure 2, p.147). We connect near and far transfer to innovativeness. Individuals with adaptive expertise who address new or unusual problem situations in their own domain, demonstrate relatively low levels of innovativeness (i.e., near transfer). Individuals with adaptive expertise have lived experience and a good understanding of that domain, enabling them to solve new problems with relatively low levels of innovativeness. Individuals with adaptive expertise who address problems outside of their own domain, demonstrate relatively high levels of innovativeness (i.e., far transfer). Here, individuals need their adaptive expertise to identify what prior knowledge and experiences may be used to meaningfully contribute to new methods and problem-solving in an unfamiliar domain. Such adaptive experts imagine possible solutions by using prior knowledge in creative and innovative ways. In short, the more distant the new domain is from your own, the more far transfer is required.

In the model, we perceive efficiency – i.e., being a routine expert – as conditional for the development of adaptive expertise. To develop towards an adaptive expert with far transfer, it is advisable to first train routine expertise, and to gradually go from near transfer to far transfer. Starting from declarative and procedural knowledge (i.e., routine expertise), one

2 In this book chapter, we use disciplines and (knowledge) domains interchangeably.

can develop conceptual knowledge which is needed to develop towards adaptive expertise (Hatano & Inagaki, 1986). Yet, following Bransford and colleagues (2005) and Schwartz (2025), we propose that adaptive expertise development requires a combination of practicing efficiency and innovativeness. One can have different levels of efficiency to develop towards adaptive expertise (Schwartz, 2025); overemphasis on efficiency can even hinder the development towards adaptivity. In this regard, Bransford and colleagues (2005) refer to the "optimal adaptability corridor" (p.51), in which the two dimensions (i.e., efficiency and innovativeness) are balanced. Therefore, we do not make a distinction in the model between 'low' or 'high' levels of efficiency. A certain level of efficiency is needed to develop towards adaptive expertise, but there is no golden standard. This also means that a learner can 'move' back and forth between efficiency and innovativeness and should practice both to develop adaptive expertise.

Learning outcomes for adaptive expertise development – The Why

We translated our model for adaptive expertise development to three learning outcomes that can be used to learn and assess adaptive expertise in transdisciplinary education.

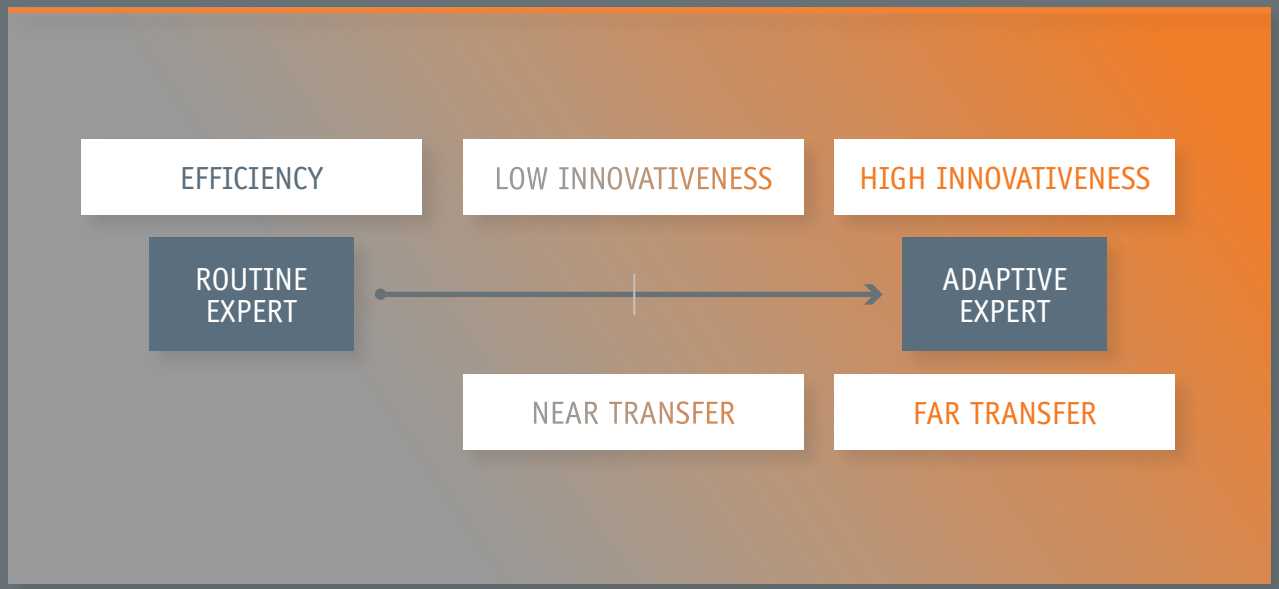
1. **Routine expertise:** The student can apply their knowledge and expertise to contribute to *meaningful* solutions to *familiar* problems in *their own problem domain*.
2. **Adaptive expertise:** near transfer: The student has an understanding of *their own problem* domain in such way that they can apply their knowledge and expertise to contribute to *meaningful* solutions to *unfamiliar* problems in that domain.
3. **Adaptive expertise:** far transfer: The student has an understanding of *problem domains that are not their own* in such way that they can apply their knowledge and expertise to contribute to *meaningful* solutions to *unfamiliar* problems in that/those domain(s).

Each learning outcome can be further specified by replacing 'domain' by a specification of the domain as targeted in a course or other educational intervention. Just as the model for adaptive expertise development, the learning outcomes have a scaffolded structure; each learning outcome builds upon the previous one. Because of the multidisciplinary, social nature of GSCs, far transfer is often needed to come to viable solutions. It takes time to develop adaptive expertise with far transfer. Next, we address how students can gradually develop towards adaptive experts with far transfer throughout their study.

Scaffolding at bachelor and master level – For Whom

Building on the model for adaptive expertise development (Figure 2, p.147), students can be stimulated to develop routine and adaptive expertise in an iterative process in which they practice efficiency and innovativeness. We suggest to carefully design education at the bachelor

FIGURE 2 MODEL FOR ADAPTIVE EXPERTISE DEVELOPMENT



and master level based on a scaffolding approach. Scaffolding is an adaptive form of teaching that suits the support of student learning in complex, uncertain learning environments, such as transdisciplinary education (Bohm et al., 2025). Students with a certain level of efficiency initially practice near transfer, and increase the level of transfer to become further as the students develop themselves over time.

Scaffolding is an interactive process between student and educator. Three main characteristics of scaffolding are contingency, fading and transfer of responsibility (Van de Pol et al., 2010). Educators adjust their support to the level of the student (i.e., contingency). They fade – decrease – the amount of support over time, aligned with the increasing level of the student. Through contingent fading, the responsibility for a task is gradually transferred to the student, which results in an increase of metacognitive skills of the student; in other words, the student takes control over their own learning. Scaffolding can help to support students to become efficient problem-solvers (i.e., routine experts), and next to develop their innovativeness by engaging in learning interventions in which they are challenged to translate their knowledge and skills to new domains and to integrate different perspectives in designing innovative solution pathways for challenges. As such, students practice their innovativeness and develop metacognitive skills, which enables them to develop towards adaptive expertise with far transfer.

This means that developing adaptive expertise with far transfer takes longer than near transfer. We encourage educators to design education in such way that students practice efficiency (i.e., learning outcome 1) throughout their studies at bachelor and master level, at different proficiency levels and in different contexts within their own domain. Students can practice innovativeness within and outside of their own domain gradually over time. In general, during the bachelor study students can practice near transfer (i.e., learning outcome 2) followed by far transfer (i.e., learning outcome 3) at the late bachelor or the master level. This can vary as students, for instance, work on more complex cases within their own domain during the master studies and more simple cases outside of their own domain during their bachelor.

Such variation in task complexity is important for adaptive expertise development (Schwartz, 2025). Whereas efficiency is developed in more stable contexts, innovativeness requires experimentation and risk-taking. By practicing innovativeness in combination with building efficiency, students develop a deep understanding of knowledge and theories, to critically reflect on the relevance of the knowledge they acquired and learn how to translate this to solve new problem situations (Schwartz, 2025). As such, students should practice efficiency in problem-solving and experiment with the development of novel methods and solutions to problem situations that are (partially) outside their own discipline throughout their studies.

Next, we discuss how adaptive expertise can be formatively assessed in education by presenting the Peradex approach, a performance-based assessment for adaptive expertise.

The Peradex approach – For Which Results

The performance-based adaptive expertise (Peradex) is a validated and reliable assessment that measures performance-based adaptive expertise by presenting students with a series of design scenarios that they need to solve (van Rijnsoever, de Jongh, & Baggen, 2026). Peradex is a more objective way to assess adaptive expertise compared to self-assessments[3].

The design scenarios were developed by extending the scenario framework proposed by Walker and colleagues (2006) to measure adaptive expertise as basis, which were developed specifically for engineering design. The Peradex assesses performance-based adaptive expertise along the two main dimensions of adaptive expertise: efficiency and innovativeness. We refer to this as respectively complexity relatedness and cognitive relatedness. *Complexity relatedness* refers to the extent to which the difficulty level of the problem at hand matches the level of expertise of the individual. *Cognitive relatedness* refers to the distance between the individuals' prior knowledge and the problem at hand. Assessing complexity relatedness and cognitive relatedness allows us to explore in what range of novelty individuals are capable to show performance-based adaptive expertise (Bohle Carbonell et al., 2016). GSCs span different domains, and can differ in complexity level. The design scenarios cover different domains and complexity levels, which allows educators to purposively challenge students to practice with efficiency, near transfer and far transfer.

The development of the Peradex scenarios

Using AI (i.e., ChatGPT), we developed 72 design scenarios across three levels of complexity and eight study areas. For each level and area, we developed 3 scenarios (3*8*3=72). Complexity relatedness was operationalized based on the International Standard Classification of Education by the UNESCO (2012). We developed scenarios for three levels of complexity: (1) Upper secondary education (high school), (2) Bachelor's, and (3) Master's. Cognitive relatedness was operationalized based on the study areas as defined by the Dutch Ministry of Education, Culture and Science (2024)[4], which resulted in the areas economics, behaviour and society, healthcare, agriculture and natural environment, nature, law, language and culture, and engineering.

3 The Peradex approach was developed as part of a research project of the EWUU Alliance, a Dutch alliance of four research universities. The alliance universities include engineering education, life sciences, social sciences, and medical sciences. The complete Peradex is available at edusources: https://edusources.nl/materials/f2663156-3362-4895-a712-a766be7a8c82/adaptive-expertise-assessment

4 We merged the categories 'education' and 'behaviour and society', because of their close relatedness. Furthermore, we removed multidisciplinary education as it overlaps with the other study areas.

BOX 1 | EXAMPLE OF DESIGN SCENARIO (AGRICULTURE AND NATURAL ENVIRONMENT; MASTER) | CHARTING NEW PATHS: ECOLOGICAL REVIVAL OF URBAN SPACES

Urbanization has significantly altered the natural landscape, often leading to a reduction in native biodiversity and the disruption of local ecosystems. As cities continue to grow, the challenge of integrating green, biodiverse spaces within urban environments has become increasingly important for ecological balance, human well-being, and sustainability. An urban area, known for its dense infrastructure and limited green spaces, is seeking innovative solutions to reintegrate nature into the cityscape.

The initiative aims to transform underutilized or neglected areas into vibrant ecosystems that support a variety of plant and animal species. This approach involves reimagining urban planning to include green roofs, vertical gardens, urban forests, and waterways that not only enhance biodiversity but also provide recreational areas for the community and contribute to climate resilience.

Problem Statement: Would you use urban planning and design principles to effectively reintegrate biodiversity into cityscapes, transforming urban areas into ecosystems that thrive alongside human activity?

QUESTIONS (try to use 5 minutes per problem case).

1. What is your **proposed solution**? Aim for a solution that is both coherent and practically viable, or describe a process that leads to such a solution (use 100-150 words).
2. How **did you get to this solution**? Discuss which knowledge and experiences (theories, concepts, developments, principles, or practical expertise) you used, and explain the reasoning behind your solution (use 50-100 words).

EXAMPLE ANSWERS

R318: Think in terms of height, there is a lot of space that can still be used up high. Plant long trees or provide beautiful ivy on the houses, it is also a good idea to build a park, which will also be good for the residents. I think people can also be called on to get more small plants, otherwise there is not much that can happen if there is no space. I think there should be more air spaces at apartments where residents can go and where it is not so gray. It might also be a good idea to wrap plants around lampposts, for example, so you use the environment and what you have. Think logically, it is difficult to plant more greenery in a very busy environment. We have the same problem in Utrecht and it is difficult to do something about it, you have to make do with what you have and in this case I think the lampposts are quite a good idea.

R444: would support technologies like sustainability roofs, energy roofs, solar PV panels and overall renewable energy technologies to produce energy in the urban areas. I would also try to build buildings with materials that have low carbon-footprint, are long lasting and doesn't cause harm to environment or biodiversity. Structures and shapes of buildings should also be designed ecologically so we can benefit as much as possible for example from the sun and get efficient water treatment. I would also suggest building green areas and parks wherever it is possible in the urban cities to improve carbon capture and utilization. Overall it is also to support actors that are able to promote sustainable manners.
This is also subject that is very relevant for my studying background. Energy efficiency of buildings, system transition, life cycle assessment calculations are all subjects that are related to the problem. Also my own passion to seek sustainable manners helped me to produce the answer. In my home country Finland, this aspect also a common subject of debate.

Each scenario consisted of a problem description, followed by standardised questions designed to elicit structured responses. The initial set of scenarios was reviewed by a panel of experienced educators, whose feedback guided further refinements of the GPT model, ensuring the consistent generation of high-quality scenarios. In Box 1, we present an example of a scenario from the field of agriculture and natural environment (master) and the standardised questions.

To evaluate the results, we employed an AI-driven pairwise comparison method using the Llama3.1:8B model. In Box 2, we provide an example of instructions for AI, including the selection of the best answer by AI for the design scenario as presented in Box 1. The instructions include rules in relation to the selection of the right answer by AI and are developed in several rounds of adapting the model. The rules are based on careful, human evaluation of the selection of best responses by AI. As AI models develop quickly, we share the instructions in Box 2 as example and inspiration; for each model, new rules must be developed fitting the output of the AI model.

The Peradex is a reliable and valid approach to measuring performance-based adaptive expertise and accounts well for cognitive relatedness, which means that it differentiates effectively between near and far transfer. Complexity relatedness, on the other hand, appeared to have only a small empirical influence on performance-based adaptive expertise (van Rijnsoever et al., 2026).

Using the Peradex in education

Peradex can be used in different ways. At the start of a course or curriculum, the Peradex approach can be used to determine students' base-line performance-based adaptive expertise. Diagnosis can inform a scaffolding approach (Van de Pol et al., 2010), informing the students and the educator about potential, next learning steps.

Next, the Peradex approach can be used to practice adaptive expertise at different moments in time throughout a curriculum. It provides students the opportunity to practice near and far transfer in a controlled environment and can be used as a formative assessment instrument (Black & William, 2009) that informs students on their proficiency to use their prior knowledge and skills in new problem situations, within and outside of their own knowledge domain.

As a course or curriculum progresses, students can work on scenarios at increasing levels of complexity and cognitive relatedness over time to reach the desired level of transfer. Especially given the complex and uncertain nature of learning in transdisciplinary education – which we elaborate on next – the Peradex approach can provide insight into students' performance-based adaptive expertise and provide the opportunity to reflect on their adaptive performance.

BOX 2 | EXAMPLE OF INSTRUCTIONS FOR AI TO EVALUATE THE RESULTS OF PERADEX FOR LLAMA 3.1:7B

INSTRUCTIONS

- You must choose the best response from the two above, identified by respondent-IDs: R318 and R444.
- Nonsensical, incoherent, or irrelevant answers must be immediately disqualified without further analysis. These can never be considered the best.
- Answers that demonstrate a clear lack of effort and understanding of the problem statement can also never be the best.
- Meaningful, detailed answers are better than generic responses.
- Evaluate both responses equally and fairly.
- First, assess the responses in the order presented. Then, reassess them with the order reversed. Compare your argumentations, weigh them equally, and base your final judgment on the most convincing of the two.
- Your final answer MUST ALWAYS begin with the respondent-id of the BEST response to the question, e.g., R072.
- Then write: 'this response is best because...,
- Ensure the respondent-id you select actually appears in the responses.
- Check that your argument for why a response is best aligns logically with the content of the response itself. If not, repeat the evaluation process above.
- Final check: Your final answer MUST ALWAYS begin with the respondent-id of the BEST response. If not, repeat the evaluation process above.

FINAL OUTPUT FORMAT

RXXX this response is best because... [your argument here] The first word of your answer must be the respondent-id of the best answer. The respondent-id always consists of the character 'R' followed by three digits. Then give a brief explanation which answer is best.

SELECTION OF CHATGPT

Response **R444** demonstrates the most adaptive expertise because it shows a deep understanding of the problem and its complexities, as well as the ability to think creatively and flexibly about potential solutions. The respondent's answer is not just a list of ideas, but rather a thoughtful and well-reasoned approach that takes into account multiple factors, such as sustainability, energy efficiency, and environmental impact.

Additionally, R444's response shows an awareness of their own background knowledge and experiences (studying energy efficiency, system transition, and life cycle assessment) and how they can be applied to the problem at hand. This level of self-awareness and ability to integrate knowledge from multiple sources is a hallmark of adaptive expertise.

Design considerations for transdisciplinary education that can stimulate adaptive expertise development – The How

In transdisciplinary education, students contribute to addressing real challenges together with peers and extra-academic stakeholders. Grand Societal Challenges (GSCs), which are complex, uncertain and value-laden in nature (Voegtlin et al., 2022), are prime examples of challenges addressed in transdisciplinary education. These challenges require students to address problems within and outside of their own knowledge domain. They need to engage with extra-academic stakeholders to develop solution pathways. Extra-academic stakeholders can be people with lived experience of the societal issue, sector experts or policymakers (O'Sullivan et al., 2025). Students are challenged to deeply understand the problem at hand, the challenge context, as well as the stakes of different extra-academic stakeholders by emphasizing with them. This is critical for solving GSCs. For instance, in the 2025 Food Systems Innovation Challenge[5] students develop nature-based solutions for local food systems, while addressing climate change and biodiversity restoration, in interdisciplinary student teams together with universities and extra-academic stakeholders from (a.o.) Bangladesh, Ethiopia, Indonesia, Vietnam and the Netherlands.

In this part of the chapter, we distinguish interdisciplinary learning and transdisciplinary learning as two underlying learning processes that are both present in transdisciplinary education and via which adaptive expertise development can be stimulated. Furthermore, it is important to consider the role of the educator in stimulating students' adaptive expertise development. We present design considerations with regard to interdisciplinary learning, transdisciplinary learning and the role of the educator that can be used to design education in such way that it fits their target group and learning outcomes. The design considerations are the final part of our teaching model framework for adaptive expertise development. We present the complete teaching model framework – which is based on constructive alignment (Biggs, 1996) – in Table 1 (p.154/155) and next elaborate the different design considerations.

Design consideration: Interdisciplinary learning

Interdisciplinary learning refers to learning across disciplinary or domain-specific boundaries (Vereijken et al., 2023). In transdisciplinary education, students are confronted with problems outside of their own discipline, which under certain circumstances can contribute to transfer. By addressing challenges outside their own domain, students can develop a deeper understanding of the disciplinary boundaries of their own domain, and to critically reflect on the relevancy of their prior knowledge and skills for new problem situations (Schwartz et al., 2012). Solving problems that are outside of

5 The Food Systems Innovation Challenge is organised by Wageningen University in 2025. For more information, see: https://www.wur.nl/en/education-programmes/current-students/student-challenge/looking-for-a-challenge/2025-food-systems-challenge.htm

THE TEACHING MODEL FRAMEWORK FOR STIMULATING ADAPTIVE PERFORMANCE IN TRANSDISCIPLINARY EDUCATION

ONTOLOGICAL LEVEL Stimulate students' adaptive performance in transdisciplinary education to enable them to help solve GSCs in meaningful ways			
	EDUCATIONAL LEVEL		
WHAT: PERFORMANCE-BASED ADAPTIVE EXPERTISE			
	Routine expertise and performance (efficiency)	Adaptive expertise and performance with near transfer (innovativeness)	Adaptive expertise and performance with far transfer (innovativeness)
WHY: LEARNING OUTCOMES			
	Learning outcome 1: The student can apply their knowledge and expertise to contribute to *meaningful* solutions to *familiar* problems in *their own problem domain*.	**Learning outcome 2:** The student has an understanding of *their own problem* domain in such way that they can apply their knowledge and expertise to contribute to *meaningful* solutions to *unfamiliar* problems in that domain.	**Learning outcome 3:** The student has an understanding of *problem domains that are not their own* in such way that they can apply their knowledge and expertise to contribute to *meaningful* solutions to *unfamiliar* problems in that/ those domain(s).
FOR WHOM: STUDENTS IN HIGHER EDUCATION			
	Students are stimulated to develop routine expertise from the start of their bachelor study. They further develop routine expertise in their bachelor and master study at different proficiency levels and different contexts within their domain.	Once students have a certain level of routine expertise, education can be designed in such way that they are stimulated to gradually practice near transfer in their bachelor study. More complex challenges within their own knowledge domain can be practiced at the master level.	Students can be stimulated to gradually practice far transfer at the late bachelor and in their master study, in which they are challenged to translate prior knowledge to new problem situations outside of their own problem domain. More simple challenges outside of their domain can be practiced at the bachelor level.
FOR WHICH RESULTS: THE PERADEX APPROACH			
USE OF THE PERADEX APPROACH	The Peradex approach can be used to determine a baseline performance-based adaptive expertise, informing the educator and the student on next learning steps. The selected design scenario matches the complexity level and study area of the student.	Variety in complexity relatedness, including complexity levels matching and (if possible) higher compared to the students' complexity level. Selection of scenarios in the own, familiar knowledge domain.	Variety of complexity relatedness and cognitive relatedness. The further away the selected domain from the own domain, the more the student is challenged to practice far transfer.

HOW: DESIGN CONSIDERATIONS			
INTERDISCI-PLINARITY	Not required.	Familiar or related domains, for instance going from electrical engineering to civil engineering. A limited amount of domains are required to address the challenge.	Unfamiliar or distant domains, for instance going from mechanical engineering to political sciences. Multiple domains are required to address the challenge.
TRANSDISCIPLINARITY	Not required.	The disciplinary background of the extra-academic stakeholders can be less distant to the background of the students to practice near transfer (e.g., a mechanical engineering student collaborates with a mechanical product engineer). Extra-academic stakeholder for instance in the (less complex) role of commissioner or project manager. Co-creation with a limited number of extra-academic stakeholders.	The disciplinary background of the extra-academic stakeholders can be more distant to the background of the students to practice near transfer (e.g., an electronics engineering student collaborates with an activistic politician to create efficient public transportation). Extra-academic stakeholder can have different roles, such as project manager or content expert. Co-creation with multiple extra-academic stakeholders.
THE ROLE OF THE EDUCATOR	The educator as domain expert who supports students to deepen their knowledge and skills in a certain domain, for instance by sharing detailed instruction, demonstrating task performance, or providing detailed feedback.	The educator as domain expert shares scientific insights, provides feedback and stimulates co-creation with others. The educator as coach monitors the learning process of the students on a regular basis, based on a scaffolded approach.	The educator as domain expert becomes a co-creator of potential solutions. The educator as coach supports students to translate their knowledge and skills to new problem situations by providing hints and cues, based on a scaffolded approach. The educator as coach also asks reflective questions to stimulate self-regulation.

the students' knowledge domain, requires students to enrich their existing knowledge and skills (i.e., efficiency), with new insights from the knowledge domain of the problem at hand (i.e., innovativeness). When the problem discipline is further away from the students' own discipline, far transfer is needed. For instance, applying knowledge and skills from electrical engineering to civil engineering requires near transfer; whereas applying knowledge and skills from electrical engineering to political sciences requires far transfer – as it entails a different understanding of how knowledge is gathered and validated, and how problems are solved.

Design consideration: Transdisciplinary learning

A key feature of transdisciplinary education is learning across different parts of society (McGregor & Volckmann, 2013). Extra-academic stakeholders and peers form an essential, though often hard-to-capture, part of the learning process. Extra-academic stakeholders can, for instance, be challenge agents or sector experts. As challenge agent, extra-academic stakeholders introduce the challenge to the students and can have an advisory role throughout the process and in the assessment. As sector experts - including people with lived experience of the impact of a challenge, such as floods which are caused by climate change – students learn to see the challenge from different perspectives (O'Sullivan et al., 2025). Through the interactions with these extra-academic stakeholders, students are exposed to alternative perspectives, potential misalignments in values, and unpredictability at the problem and solution-side (Visscher et al., 2022). This encourages them to truly empathise with others, which enables them to gain a deep understanding of the problem context, and what it means for different stakeholders involved. Further, they co-create possible avenues for solving the issue with these extra academic stakeholders, from which they learn to develop viable, new and innovative solutions, which fit the context and specific problem situation at hand. As such working with extra-academic stakeholders helps them to develop their innovativeness and learn to become adaptive experts.

Although it is hard to capture near and far transfer in transdisciplinary learning, we expect that in general the disciplinary background, the function and the level of engagement of the extra-academic stakeholders plays a role in this regard. The disciplinary background can be close or more distant from the disciplinary background of the student. Further, it might be more challenging to work together with an extra-academic stakeholder in the role of content expert (distant to the student's disciplinary background), compared to an extra-academic stakeholder in the role of project manager. Lastly, the level of co-creation with extra-academic stakeholders can differ. We expect that the co-creation of solutions together with a wide variety of extra-academic stakeholders across different disciplines and Organisations can stimulate adaptive expertise development with far transfer. Also here, it is important that the educator aligns the level of complexity and uncertainty in the learning process with the target group and learning outcomes, based on a scaffolded approach.

Design consideration: The role of the educator

The role of the educator in transdisciplinary education is complex and not always clear to the student and the educator themselves (O'Sullivan et al.,

2025). We distinct three roles educators can have in transdisciplinary education: the educator as domain expert, coach and co-creator of solutions. Based on a scaffolded approach, it is important that the educator matches the teaching strategy to the situation at hand and the response of the students (Van de Pol et al., 2010). Bohm and colleagues (2025) name three techniques to scaffold students towards problem-solving in uncertainty.

First, educators can mark critical features to support students task performance, for instance by checking if students understand given feedback. Second, direction maintenance can help students develop their metacognition, for instance when students and educators discuss the potential effects of certain solution pathways. Third, with frustration control educators can help students to deal with the potentially overwhelming amount of uncertainty students have to deal with in transdisciplinary education, particularly at the start of addressing a societal challenge. Educators can use these scaffolding techniques in their different roles.

To build efficiency, the educator as domain expert can for instance provide detailed instruction, demonstrate a complete procedure or solution, or provide detailed feedback on task performance. To build innovativeness, the role of domain expert becomes less important, as students master their expertise themselves. Rather the educator can provide hints or suggestions to find analogies between the domain knowledge of the student, and the problem at hand, to come to a solution. Here, the educator could also take the role of co-creator of potential solutions, as the expertise of students and educators becomes more alike, and can participate in joint efforts in creating the best solution. As coach, the educator can focus more strongly on the learning process, and how students solve problems outside their domain while working with extra-academic stakeholders. Initially, the educator as coach can monitor the learning process of the student. When the students develop towards far transfer, the educator as coach can have a more facilitating role, ask reflective questions, and encourage students to empathise with others, so that they learn to steer their own learning. Such coaching can accelerate students' understanding of the value of different perspectives to the problem and use such input to develop more meaningful solution pathways. Especially given the uncertain nature of learning – the co-creation of solution pathways with extra-academic stakeholders is unpredictable and full of so-called learning surprises (Baggen et al., 2022) – we expect that the role of the educator as coach compared to the role of the educator as domain expert increases in importance when students develop towards adaptive expertise with far transfer, to help the students to learn the most from such learning surprises.

Pelzer, Hoffman and Hajer (2024) shared their experiences with mixed the classroom in which students and practitioners (i.e., extra-academic stakeholders) learn together and co-create solutions for societal problems. Pelzer and colleagues (2024) refer to their role as 'tinkering'; ongoing reflective processes on learning (i.e., pedagogies) on the one hand and institutional dynamics (i.e., conflicting dynamics of education and practice) on the other. In this article, they reflect on the "good deal of

uncertainty" (p. 8) they had to deal with and the importance of failure in creating such education. Further, Bohm and colleagues (2025) found that educators struggle with diagnosing team dynamics and students' personal development in group processes, which may hinder educators to apply different scaffolding strategies. The role of the educator in transdisciplinary education is changing and higher education institutions should carefully consider how to prepare and facilitate their educators best. Not only students are challenged to deal with uncertainty, but also educators. It might help to work together in teams consisting of a variety of educators, for instance with experience outside of academia, having adaptive expertise with far transfer themselves, and novice educators for whom it might be easier to empathise with the students.

Concluding remarks

In this chapter, we developed a model for adaptive expertise development integrated with the issue of transfer in transdisciplinary education. Further, we presented learning outcomes with a scaffolded structure, addressed how students can gradually develop adaptive expertise with far transfer in transdisciplinary education and discussed the Peradex approach which can be used for formative assessment purposes.

We conclude this chapter with a call to researchers and educators to further use, test, and develop the design considerations for adaptive expertise development and create constructively-aligned transdisciplinary education. Also, inspirational practices can help to further illustrate how adaptive expertise development can be translated to educational practice. Specifically, the use of the Peradex approach can be further explored for formative assessment purposes in education. The Peradex approach is accessible online [6]. With the current chapter we aimed to provide concrete suggestions on how to design constructively-aligned transdisciplinary education that enable students to practice adaptive performance as a key capability to help solve GSCs.

6 https://edusources.nl/materials/f2663156-3362-4895-a712-a766be7a8c82/adaptive-expertise-assessment

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10 | Adaptive performance: a promising concept for engineering education?

Photo: Joonas Sild | Unsplash

10 | Adaptive performance: a promising concept for engineering education?

P. den Brok *

ABSTRACT **In this discussion chapter of the book, first the concept of adaptive expertise is reflected upon. It is argued that its skills- and task-based nature has particular strengths for the design of education and learning, such as its underpinned and structured nature of approaching complexity. But it also has some limitations or potential risks, such as an under-emphasis on affective processes, the balance and choice for certain tasks or the risk of relying on potentially limited expert views.**

Second, the chapter discusses characteristics of adaptive expertise in practice and its implications for educational design. Such implications include designing for open and meaningful situations, encouraging learner agency and ownership, integrating social, physical and technological contexts and stimulating formative assessment.

Third, the chapter concludes that adaptive expertise and engineering education might form a happy marriage given their focus on complexity, project- and problem or challenge based approaches, and their balance between skills and knowledge.

The chapter ends with some suggestions for future research, such as on the nature, combination and balance of tasks needed in education and its positioning within the curriculum.

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Introduction

This book brings together a nice and contemporary set of papers on the role of adaptive performance in higher engineering education. After an introduction of the concept (Van den Beemt et al., chapter 1), **the chapters in the first part of the book link the concept to underlying mechanisms in different contexts of work-based learning environments** (Groenier et al., chapter 2; Munneke & Ommering, chapter 3; Kaffka & Backhaus, chapter 4 and Jensen & Gamborg, chapter 5)**. In the second part, the authors describe how adaptive performance can be stimulated** (Kaffka et al., chapter 6; Van Bruggen et al., chapter 7)**. Part II describes formative assessment of adaptive performance** by Pennings et al. (chapter 8) and Baggen et al. (chapter 9).

In this discussion chapter, the conceptual background of the concept of adaptive performance will be further discussed. What was or is its conceptual origin, and how do the different chapters in this book adhere to or expand this origin? What can be seen as strengths of the concept in this respect? But also, what conceptual questions does the concept raise, and what does this mean for its use? Next, the main characteristics of the concept will be highlighted, as they come to the fore across the different contributions in this book. What do these characteristics imply for the learning environment, the role of the teacher (and student), and the curriculum? Finally, a reflection will be given on the fact if there is indeed a good marriage or link between the concept of adaptive expertise and engineering education. Finally, some suggestions for future research on the topic of adaptive performance in engineering education are provided.

Reflections on the nature of the concept of adaptive performance

In the introduction chapter of this book, following Ericsson et al (2018), van den Beemt et al. (this book) 'define' adaptive performance as the outcome of the ability to deal with tasks that are complex, uncertain and new, and for which routine and standard operating procedures are not sufficient, based on cognitive structures resulting from experience. Note that the authors do not directly or explicitly provide this definition, but it can be pieced together based on their definition of expertise and their discussion of complex problems in the context of engineering education, which are described as uncertain, unpredictable, ill-structured, abstract and requiring interdisciplinary, authentic, student-centred approaches, such as challenge-based learning. According to the authors, adaptive expertise underlies adaptive performance, which is the actual and successful dealing with uncertainty in complex tasks.

This definition unobscures that abilities are central, and the book highlights several of these abilities, such as (deep) reflection (on content, processes and experiences), creative and critical thinking, self-regulation and metacognition, being able to apply (see for example the chapters of Jensen & Gamborg and Kaffka et al. in this book). These abilities can

be developed through experiences in dealing with tasks. As such, the concept finds its origin in research on intelligence, task performance and the role of processing information as part of this and has a strong cognitive psychology background – suggesting that (complex) tasks trigger knowledge structures or networks in individuals, structures based on prior performance and knowledge.

Obviously, this cognitive and task-based approach has several advantages for the design and setup of learning environments. Tasks can often be analysed in terms of steps, constituting parts and skills, and linked to actual and authentic professional situations. This leads to clear design criteria and structured approaches for training learners. Several other frameworks take such an approach as a starting point and are discussed in this book as well, such as the 4-CID model for complex skills development (van Merriënboer et al., 2002), or theories on self-regulation and meta-cognition (Zimmermann & Schunk, 2011; Zimmermann, 1986; Winne & Hadwin, 2008).

To some degree, more contemporary variants of these approaches, such as challenge-based learning, case-based learning, scenario or design-based learning, also seem to start from authentic situations and tasks, and the skills and knowledge needed in these. Most of these theories and models are well-researched and provide a sound theoretical basis for adaptive performance and its development in learning environments. Also, the concept of adaptive performance seems to align well with contemporary and relevant approaches in engineering education, such as challenge-based learning and workplace learning, and also aligns well with views on engineers of the future, including the T-shaped profile (Tranquillo, 2017) – see also next sections.

Interestingly, the different chapters in this book seem to expand the concept of adaptive performance and its task-based, cognitive origins quite easily to new paradigms and approaches, such as socio-constructivism, socio-cultural theory or boundary crossing. In doing so, they put more emphasis on elements such as the need for collaboration and shared knowledge or expertise, the role of tools and resources, and the role of individual perceptions and meaning making (see for example Kaffka et al., and Munneke & Ommering in this book). Also, such theories seem to advocate a stronger agency and active role for the learner. This expansion brings an interesting tension to the fore within the concept of adaptive performance.

Within this field of research, there is an interesting debate on the interplay between the role of the individual and their characteristics, the role of the task or environment and its characteristics and the social nature of developing adaptive performance (Pelgrim et al., 2022). Most research seems to situate adaptive performance mainly as a quality of the individual, in particular related to its cognitive and metacognitive nature, thereby following the more traditional origins of the concept. However, scholars such as Engeström (2018) debate this and propose that expertise is not a quality of the individual, but resides in activity systems, which consist of a group of objects and tools, and are conducted in a

community of practice. In doing so, they suggest that the task and context element of the concept are perhaps more important than more cognitive oriented scholars would propose. Obviously, putting more emphasis on one of these elements in the interplay between individual, task, and context also has potential consequences for how one conceives the development of adaptive expertise (see next section).

Next to this, the cognitive and task-based nature of the concept of adaptive performance also raises several questions and issues. First, there seems to be a central emphasis on the cognitive and behavioural aspects of learning, and to some degree the metacognitive or regulative aspects of learning; much less attention is paid to the affective or emotional dimensions of learning of tasks, or to the personal side of learning, including professional identity (development), values, ethics or motivations (cf. Vermunt & Verloop, 1999; Zimmermann & Schunk, 2010). Interestingly, uncertainty seems to be a relevant starting point in tasks in most chapters in this book, but uncertainty can have different origins, relating to, for example, a lack of knowledge, knowledge that brings tensions or dilemmas, a lack of process overview, or working with unfamiliar practices (Bohm et al., 2024).

Interestingly, most experts are inclined to focus on cognitive related uncertainty, while many tasks seem to bring emotional and affective uncertainty as well, requiring different types of support (Bohm et al., 2024). While such elements are under-researched in challenge-based learning and engineering education in general, they also seem underrepresented in adaptive performance research, and are only to a limited degree addressed in the contributions in this book as well.

Second, while tasks and experiences are relevant to show expertise and being able to respond well to a variety of situations and problems, the question arises if all situations tasks are equally relevant and suitable to develop adaptive expertise, and if not, which situations and problems should be prioritized, how they should be balanced and placed within a curriculum. Pelgrim et al. (2022) also note this based on their review of the literature on adaptive performance: they refer to work by Ward et al. (2018) who argue that there is no clarity as to how new or large a task needs to be in order to require or develop adaptive expertise. Some tasks may be so new and complex that even experts (including adaptive experts) cannot easily solve them – they refer, for example, to the way people had to deal with the 9-11 or Covid-19 circumstances.

Also, the question as to whether a task needs to require only disciplinary knowledge or also interdisciplinary knowledge, according to them remains unanswered. This brings another interesting question, as to whether an adaptive expert needs to be a disciplinary specialist or an interdisciplinary one. Ward et al. believe that disciplinary knowledge already allows an expert to be flexible, whereas other scholars would argue that interdisciplinary knowledge and expertise are also needed before one can be an adaptive expert.

In this book, most authors and chapters argue that tasks relevant

to adaptive performance are inter- or transdisciplinary in nature. However, the number of disciplines involved in a task and the degree to which these disciplines or domains are more distant or more adjacent to each other differs, and the role this plays in the development of adaptive expertise remains unclear.

Third, the focus on experts and their cognitive structures have the advantage to detect relevant and central concepts or procedural schemes. However, the practical knowledge of experts may also be subject to misconceptions, ill-defined concepts or procedures, narrow viewpoints, and be constrained to a set of situations that is relatively constrained in nature (Brants, 2013; Quirk, 2010). This highlights the importance of theoretical knowledge as well as relevance of involving multiple experts in learning environments.

Ultimately, these issues also raise some more philosophical questions for education. Should every graduate in higher education strive to become or be developed towards an adaptive expert? Are there different types of adaptive experts, for example, more disciplinary and interdisciplinary ones? Is there a stronger need to focus not only on the cognitive and task-based nature in developing adaptive expertise, but also on the personal, affective and social aspects of expertise development, and in doing so expand the development of adaptive performance in higher education beyond a mere qualification function, to also include a socialization and subjectification function (Biesta, 2020).

The concept of (developing) adaptive performance in practice

While the different chapters in this book highlight a variety in contexts and situations and emphasise different types of skills under adaptive performance, there seems to be a common set of characteristics and criteria that underlies the different learning environments discussed.

Characteristics that emerge from the different chapters of the book are:

- Unfamiliar, complex and open-ended tasks or situations, where there are multiple solutions possible or where solutions always have certain advantages and disadvantages.
- Situations or problems that require a variety of disciplines or domains, different types of expertise, and that are sometimes transdisciplinary in nature. Most of these tasks or approaches, therefore, require some type of collaboration, often involving boundary crossing.
- Task performance often requires tools or other resources. Typically, a design-based, research-based or other type of cyclical approach is needed. Due to the often project-based nature, aspects such as pragmatism or an agile approach are also relevant.
- Activities require the performance of a variety of deep learning skills, such as reflection and self-regulation, creative or critical thinking, logical reasoning, application or abstraction.

- The role of the teacher often emphasises coaching, which is focused on a variety of things, such as content, process, emotions and outcomes. Providing timely and flexible stimulating feedback is essential. This requires the ability to be flexible in content, maintain overview and look at learning in a holistic way. But it also requires from teachers to be able to create networks, work with a variety of stakeholders, the ability to create complex tasks.

- Assessment of learning often focuses on both short-term and longer-term processes, has a programmatic nature, emphasises formative approaches, requires feedback literacy, allowing for a variety of potential outcomes, even learning surprises, and needs to be inclusive, distinctive and include elements such as collaboration and self-regulation. In the end, quality of processes and outcomes is more important than efficiency of performance.

The authors of the different chapters emphasise that adaptive performance is central to their approach and can be suitably translated into environments and conditions that are conducive to learning. Also, there seems to be agreement among the central characteristics and elements involved. Overall, the approaches mentioned seem to suggest that deliberate practice is important (see also Bronckhorst et al. 2011; 2014; van Dijk et al., 2023). This implies that education needs to engage learners in tasks that require effort, concentration, that stimulate self-improvement and that repeated practice is needed. In addition, to stimulate the deliberate nature, sufficient attention needs to be provided to the development of theoretical knowledge in learners, linking this theory to existing knowledge structures of learners, and stimulate reflection, also by providing feedback.

This book implies several areas for educational design:

First, the design for complexity in open, meaningful situations. In the cases discussed, students worked on open-ended, often multidisciplinary challenges that forced them to: 1) apply and develop (existing) knowledge, 2) arrive at new insights together with others, and 3) learn to deal with ambiguity, failure and uncertainty.

Second, to encourage epistemic ownership and agency. Several contributions, e.g., Munneke & Ommering, highlight the importance of epistemic agency : the ability and willingness of students to actively and consciously create knowledge, rather than just reproduce knowledge. This requires students to feel co-ownership of their learning process, and to learn to deal with knowledge uncertainty. For education, this requires the stimulation of making your own choices (autonomy), to be able to negotiate goals or success criteria, and to actively reflect on assumptions, perspectives and results.

Third, to weave social, physical, and technological contexts. Several chapters make it clear that learning is not just a mental activity. Instead, it is *ecological, embodied and relational*. Cognition takes place in interaction with people, objects, technologies and spaces. For example: the role of collaboration in agile working methods (Kaffka et al., this book), the

influence of physical actions on learning (Jensen & Gamborg, this book) and the importance of teachers guiding safe and meaningful interactions (Van Bruggen et al., this book).

Finally, making the case for formative assessment. Although adaptive performance is difficult to grasp, the chapters of Pennings et al. and Baggen et al. show that it is indeed possible to make adaptive performance visible. The adaptation of the D-ADAPT instrument shows how perceptions of adaptive capacity can be mapped. The use of generative AI opens new doors: scenario-based simulations generate realistic contexts in which adaptive performance can be evaluated. This implies that measurement instruments should not only focus on the *end product* of adaptive action, but also on the *processes* that precede it: perspective change, metacognition, reflection, and learning process.

Although this agreement on the main elements and characteristics needed for the development of adaptive expertise is helpful, it does not answer questions as to how adaptive expertise needs to be placed within the larger curriculum. Earlier in this chapter, questions were already raised as to whether the curriculum needs to develop everyone into some kind of adaptive expert? Are the approaches mentioned suitable for all learners? If we agree on the importance of developing adaptive performance in higher education, where and how in the curriculum should it be placed? Is it, given its focus on complexity and authentic, work-based situations, and the complex nature of skills involved, the best place at the end of a curriculum?

As mentioned, some suggest that adaptive performance requires a strong disciplinary basis and requires learners to have a strong theoretical basis. If so, how does this requirement, for example, align with the development of broad bachelors' that is occurring at most Dutch universities? How does the holistic, programmatic and quality focused nature of learning and assessment that is mentioned to develop adaptive performance align with the current focus in most universities on grades, efficiency and summative assessment? How to incorporate elements that go beyond the cognitive nature of adaptive performance? How can students be best prepared for adaptive performance, and what could potential learning trajectories look like?

And finally, is the approach painted in the various chapters mainly or uniquely suitable to the context of engineering education, and is it a typical Western concept or approach – note that the vast majority of the authors and their work originate from the Netherlands? This final set of questions nicely brings us to the final topic of this discussion, the fit with engineering education.

Adaptive performance and engineering education: a happy marriage?

The introduction chapter of this book emphasises the relevance of the concept of adaptive performance for the context of engineering education. In their argumentation, the authors mention the fact that many engineering education institutes focus on complex, real-life, societal problems, for example related to sustainability, health, food or energy, that on the one hand require technological expertise, and on the other hand expertise on a variety of other domains. In addition, the authors mention the focus on innovation and creative thinking, and an entrepreneurial mindset, elements that are also central to engineering education. They further refer to elements such as logical thinking, validation, accuracy, but also the need for design based and scenario-based approaches. And they mention approaches such as challenge-based learning, which are highly popular in engineering universities, and that seem to align well with the authentic, work-based approach to tasks and task performance.

The concept of the adaptive expert, who has a well-developed cognitive structure based on their experiences in real-life tasks, and who is able to link this structure to non-routine tasks requiring complex skills, aligns well with the image of the T-shaped and Phi-shaped engineer, an engineer who has specific expertise and knowledge in one domain, but who is able to collaborate with others and link him- or herself to other domains and practices (Tranquillo, 2017). The idea also aligns well with the distinctions that several universities make in potential graduate profiles, and that further stress the development of particular knowledge and expertise, such as that of a technical expert, an entrepreneur, a policy or decision maker, a teacher, and so on.

As can be seen in the above list of characteristics, many elements of adaptive performance and its implementation in higher education are also typical for engineering education, as already indicated in the introduction chapter of the book itself. Think of design-based approaches, systems thinking, creativity, dealing with complex problems, project or problem-based approaches, challenge-based learning, the use of tools and resources, and so on.

That said, some elements of adaptive performance, certainly when approaching it to its full extent, encompassing some of the limitations mentioned earlier on, are less common or perhaps deemed more challenging for engineering education teachers. These elements are, for example, the need to focus more on emotions and the affective side, the need to focus on the personal side, including ethics and personal values, but perhaps also the need for collaboration and the need for inclusivity, including working with less technical domains. One may finally wonder to what degree adaptive performance should be part of the curriculum, and to what degree all teachers at engineering universities should possess all the qualities and characteristics of coaching as mentioned earlier.

Overall, the marriage of adaptive performance with engineering education seems a happy one, although its relationship needs to be further developed in the future.

Future research

This book provides a good starting point for those interested in developing adaptive performance in education, especially in the context of engineering education. It shows that the concept aligns well with contemporary ideas of engineers that need to be prepared for the challenges of the future, and that embracing it to its full extent aligns well with many educational trends that have been picked up in engineering education. The case studies and projects described in this book help to understand its versatile nature and support the empirical knowledge base behind the construct.

As can be seen from previous sections in this discussion chapter, a book such as this only provides a first step, and more research on the concept and its application is needed in the future. These include investigating the relevance and applicability of adaptive performance outside the context of the Netherlands and engineering education. More conceptual development is needed as well: to what extent should the concept evolve beyond its cognitive and task-based nature? Do other frameworks, such as socio-constructivism, help to develop the concept to include elements such as affect and emotions, personal development, and link the more individual cognitive approach to more shared or collective broader approaches?

Finally, much more research is needed to make the concept better implementable in practice. Questions that could be addressed are: what balance should be struck in the curriculum between more routine-based and non-routine-based tasks? Should all graduates be developed towards adaptive experts? What level of (prior) knowledge is needed to develop adaptive expertise and to what degree can or should this knowledge be monodisciplinary or multi- or interdisciplinary? Where in the curriculum can adaptive performance be best developed, and what should learning-lines look like that prepare students towards adaptive performance? What tasks are most suitable to develop adaptive performance, and how complex (or not) should they be in terms of nature and number of domains of expertise involved? What type of assessment is needed? How can we best prepare university teachers for the different nature of coaching and assessment that adaptive performance requires?

Finally, how does adaptive performance and its current nature position itself to other approaches that start to emerge in science, such as regenerative or transformative approaches? Such approaches deviate from the idea of power structure and traditional (often Western) approaches to knowledge and knowledge development, bring whole person development to the fore, and emphasise different outcomes than the technological-economic paradigm.

> *It is exciting to see the developments presented in this contemporary book! Undoubtedly, this book is the first in a line of many to come in the future, as the topic of adaptive performance is just kicking into gear.*

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Jan Onne Backhaus studied civil engineering before moving into the Hamburg aircraft construction industry, where he led R&D projects as a structural engineer. His last role in the sector was Director Offshore. Driven by academic interests, he pursued an Executive MBA at the School of Economics and Management (FOM), completing the programme in 2017. During this time, he also began his doctoral research at the Technical University of Hamburg and started consulting companies on intercultural communication and project management.

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In his teaching and research, Jan focuses in particular on teachers and the development of their expertise. Together with colleagues, he has been conducting research for many years into how teachers develop expertise in building positive interpersonal relationships with pupils. He and his colleagues are also studying the adaptability of teachers to changing or new circumstances and challenges. In Utrecht, Jan is one of the leaders of the university's Higher Education Research focus area, and together with colleagues from the universities of Helsinki and Oxford, he is currently editing a handbook on the results of research into higher education, which will be published by Routledge in 2026.

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She received a Comenius Leadership Grant for the development of educational design principles for student-driven authentic learning environments. She is the project leader of a national research consortium on transdisciplinary education.

Chapter 1

Introduction: Adaptive performance in engineering in times of uncertainty and change

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Chapter 2

Complex work-based learning environments for adaptive expertise development in engineering education: Lessons from three cases in Dutch higher education

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Enhancing adaptive performance through developing epistemic agency and research competencies

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Development of engineering students' adaptive performance using agile methods: The case of Drees & Sommer SE

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Empowering university educators: How Q-sorting fosters adaptive expertise and professional development

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Chapter 7

Building engineering students' adaptive performance through challenge-based learning: a sensemaking perspective

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Adaptive expertise: a promising concept for engineering education?

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Colophon

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