2.5

Engineering Leadership Development: An Integrated Framework for Practice

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

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1 Introduction

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

1.1 What do we mean by engineering leadership?

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

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

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

1.2 Why engineering leadership matters

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

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

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

1.3 Three complementary approaches to engineering leadership development

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

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

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

1.4 How do the models work together?

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

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

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

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

2 Leadership Paradox Compass

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

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

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

2.1 Origin of the model

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

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

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

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

Table 2.5.3: Leadership paradoxes used in the Leadership Paradox Compass

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

The model is further informed by empirical analysis of LPI data from 240 participants in Poland, including leaders, non-leaders, and engineering students (Marjańska et al., 2024). Findings suggested that leadership development involves increasingly differentiated and paradox-aware judgement, with some paradoxes spanning multiple LPI dimensions. Tables 2.5.2 and 2.5.3 present the leadership dimensions and paradoxes used in the model.

2.2 Description of the model

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

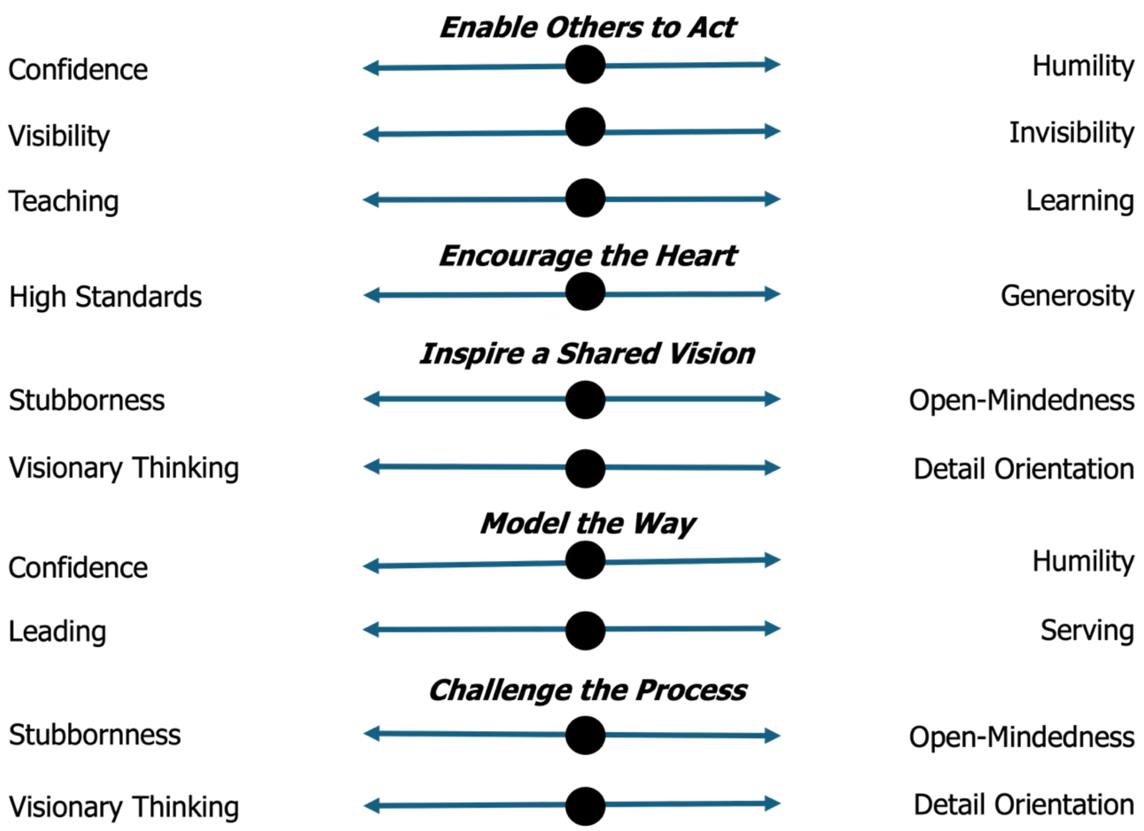

Figure 2.5.1: Leadership Paradox Compass: navigating tensions across five dimensions (elaboration by authors based on Elmore, 2021 and Kouzes & Posner, 2003)

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

The model is designed as a practical reflection tool. Educators can use it as a handout, discussion prompt, or team-based teaching aid to help learners analyse real engineering situations, explore leadership tensions, and discuss how different responses may influence team dynamics and outcomes.

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

2.3 Application of the model

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

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

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

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

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

3 Engineering Leadership Orientations (ELO)

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

3.1 Origin of the model

The Engineering Leadership Orientations (ELO) model was developed by Rottmann et al. (2015) through a mixed methods grounded theory study of leadership development in engineers' professional practice contexts. Drawing on survey and focus group data from more than 250 Canadian engineers working in four technically-intensive organisations, the project team found that resistance to leadership decreased when leadership orientations were grounded in engineers' professional practice experiences. This professionally relevant model resulted in three compound engineering leadership orientations: technical mastery, collaborative optimisation, and organisational innovation (Rottmann et al., 2015). The orientations were subsequently tested using a 31-item survey with 175 Canadian engineers (Reeve et al, 2015). All three scales passed social science reliability thresholds (Cronbach's alpha ≥ 0.7) (Kline, 1999). This social science reliability measure indicates that the initial model, which was based on our qualitative analysis of small-scale focus groups, held up statistically with a larger sample of engineering professionals working in four different industries — software, mining, consulting, and chemical processing.

3.2 Description of the model

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

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

3.3 Application of the model

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

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

Because the model is grounded in engineering identity rather than abstract leadership theory, it can be particularly effective for learners who perceive leadership as peripheral to engineering practice. It also offers a practical entry point for engineering educators who may feel hesitant to integrate leadership development into technically focused teaching.

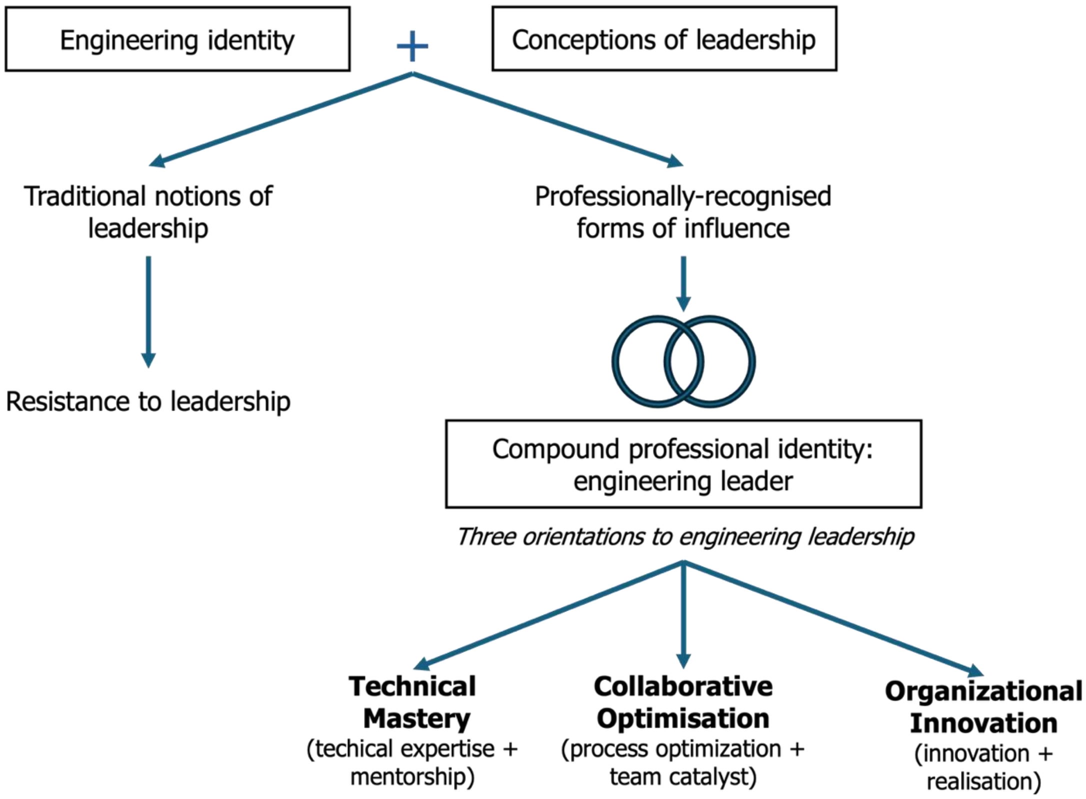

Figure 2.5.2: Engineering leadership orientations
Exclusive rights by SAGE, published with permission — from Rottmann, et al. (2015). Engineering leadership: Grounding leadership theory in engineers' professional identities. Leadership, 11(3), 351-373.
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Engineering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

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

4 Contextual Engineering Leadership Development (CELD)

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

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

4.1 Origin of the model

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

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

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

4.2 Description of the model

The CELD conceptualises leadership preparation as a set of concentric circles of expanding impact, as illustrated in Fig. 2.5.3. At the centre of the model, effectual behaviour emphasises self-awareness, awareness of others, and the ability to act despite incomplete information. It includes recognising knowledge limitations, seeking feedback, advocating for ideas, and adapting decisions as circumstances evolve. The second layer, teaming, positions leadership as a distributed and relational process rather than a formal role. Leadership in this context involves contributing to shared work, enabling the contributions of others, and creating conditions for effective and equitable collaboration. The outermost layer, contextual awareness, expands leadership beyond immediate team performance to the broader consequences of engineering work. It encourages learners to consider the social purpose, ethical implications, and systemic effects of engineering decisions, recognising that technical work is always embedded within wider human contexts. Across all layers, engineering technical mastery remains foundational. However, the model explicitly rejects the idea that technical expertise exists in isolation. Technical competence is enacted through individual judgement, expressed through collaboration, and shaped by contextual understanding. Taken together, the model presents leadership development as a developmental process in which individual agency, teamwork, technical competence, and contextual responsibility become increasingly integrated as learners progress.

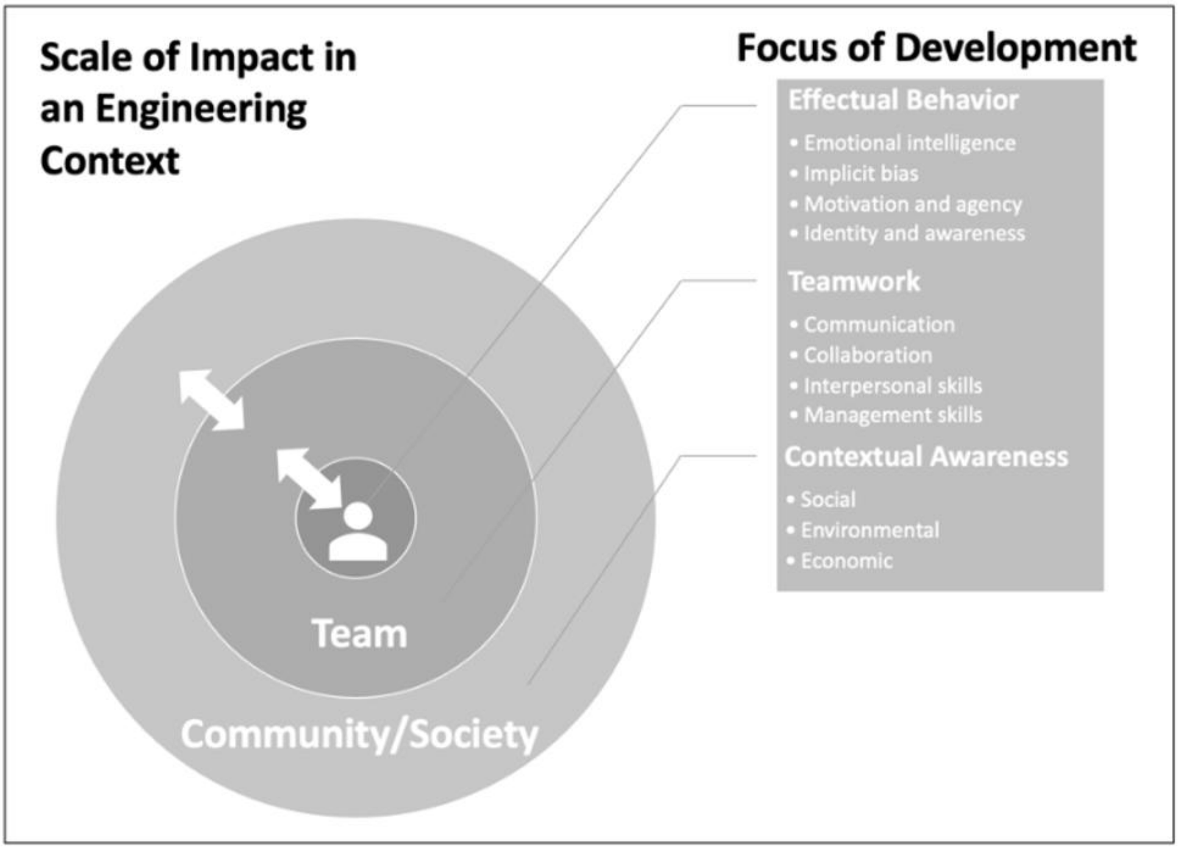

Figure 2.5.3: Contextual Engineering Leadership Development framework (elaboration by authors based on Kendall et al., 2018)

4.3 Application of the model

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

A key strength of the model is its adaptability. Developed across diverse institutional contexts, it was intentionally designed to be transferable across different programme types, institutional missions, and pedagogical approaches. Although the original case studies placed strong emphasis on team-based engineering design, the framework is not tied to any single instructional method.

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

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

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

5 Cross-case summary of ELD models

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

5.1 Points of convergence across the three models

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

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

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

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

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

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

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

5.2 Practical implications

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

6 Implications and recommendations for EL development in engineering education

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

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

6.1 Consider learners developmentally and contextually

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

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

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

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

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

6.2 Consider how you frame leadership

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

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

6.3 Be intentional about learning goals

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

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

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

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

6.4 Design for engagement, practice, and feedback

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

Example 3: Professional identity development: ELO inventory

At the University of Toronto, Canada, we introduce students and professionals to the ELO model by asking them to complete a 15-item inventory derived from a subset of survey items with high factor loadings. We generated two inventories — one geared to professionals and the other adapted for students. The inventories allow participants to explore their own leadership orientations, connect with others who have similar orientations to examine their strengths and weaknesses, and pivot to other orientations when necessary. The questions are easy to answer, and the inventory is set up for self-scoring, making it an accessible entry point for students and professionals who may not see themselves as leaders. The ELO inventory provides engineers with conceptual anchors related to their own leadership orientations, but like any other pedagogical tool, we needed to actively help participants make sense of the ways these conceptual anchors are tethered to their everyday lives and organisational contexts. The inventory is not proprietary but is *minimally useful on its own. We encourage interested engineering educators to help their students connect theory to practice by reading the original article (Rottmann et al., 2015) and reflecting on their orientations in project team and organisational contexts.*

6.5 Consider educator and institutional capacity

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

6.6 Resources and further reading

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

7 Conclusions

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

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

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AI statement

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

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