Engineering: Moving leadership from the periphery to the core of an intensely technical curriculum

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Engineering educators have developed extensive leadership learning opportunities to support the socio-technical development of their students. A contemporary challenge is to integrate leadership learning into foundational coursework requirements.

Chapter 8

Engineering: Moving Leadership From the Periphery to the Core of an Intensely Technical Curriculum

Mike Klassen, Doug Reeve, Greg J. Evans, Cindy Rottmann, Patricia K. Sheridan, Annie Simpson

Overview of leadership within engineering

Engineering is a "hard applied" professional field (Muller, 2009) that mobilizes a deep understanding of mathematics and natural sciences to meet sociotechnical challenges. The form and focus of engineering education have changed significantly over the past century, from apprenticeship-style practical education to an academically oriented theoretical curriculum (Harwood, 2006). Today, the undergraduate degree is the key qualification for entry into supervised professional practice, offering a theoretical background in mathematics and relevant sciences as well as an introduction to engineering design. Engineering has thrived over the last fifty years, with enrolment growing substantially in both undergraduate and graduate programs. Engineering has expanded into a wide array of sub-disciplines from classics such as civil, mechanical, electrical and chemical engineering into newer fields such as aerospace, computer, materials science, biomedical and even financial engineering.

Engineering leadership education. Historically leadership education in engineering has been implicit and assumed to be learned on the job. Over the course of the twentieth century, as curriculum emphasis has shifted from hands-on practical topics to more sophisticated mathematical modelling of scientific phenomena, leadership has been largely ignored as a legitimate subject for undergraduate students (Divall, 1994). However, in the past 20 years, the pendulum has begun to swing back towards practice. As providers of professional education, engineering schools must apply for accreditation of their degree programs so their graduates can qualify for entry into professional practice as licensed Professional Engineers. This accreditation process creates both opportunities and challenges for leadership champions within the discipline.

Competencies and learning outcomes. Professional bodies and accreditation boards across national jurisdictions have recently required a wide array of “non-technical” student learning outcomes, such as design, communication, ethics, equity and teamwork, for degrees to be accredited (Volkwein, Lattuca, Harper, & Domingo, 2007). A curricular consequence of these broader shifts has been a marked increase in the use of team design projects across all disciplines of engineering (Case, 2014). While leadership training has not always been integrated into design team projects, these open-ended, collaborative projects have opened the door for leadership education at the periphery of the curriculum.

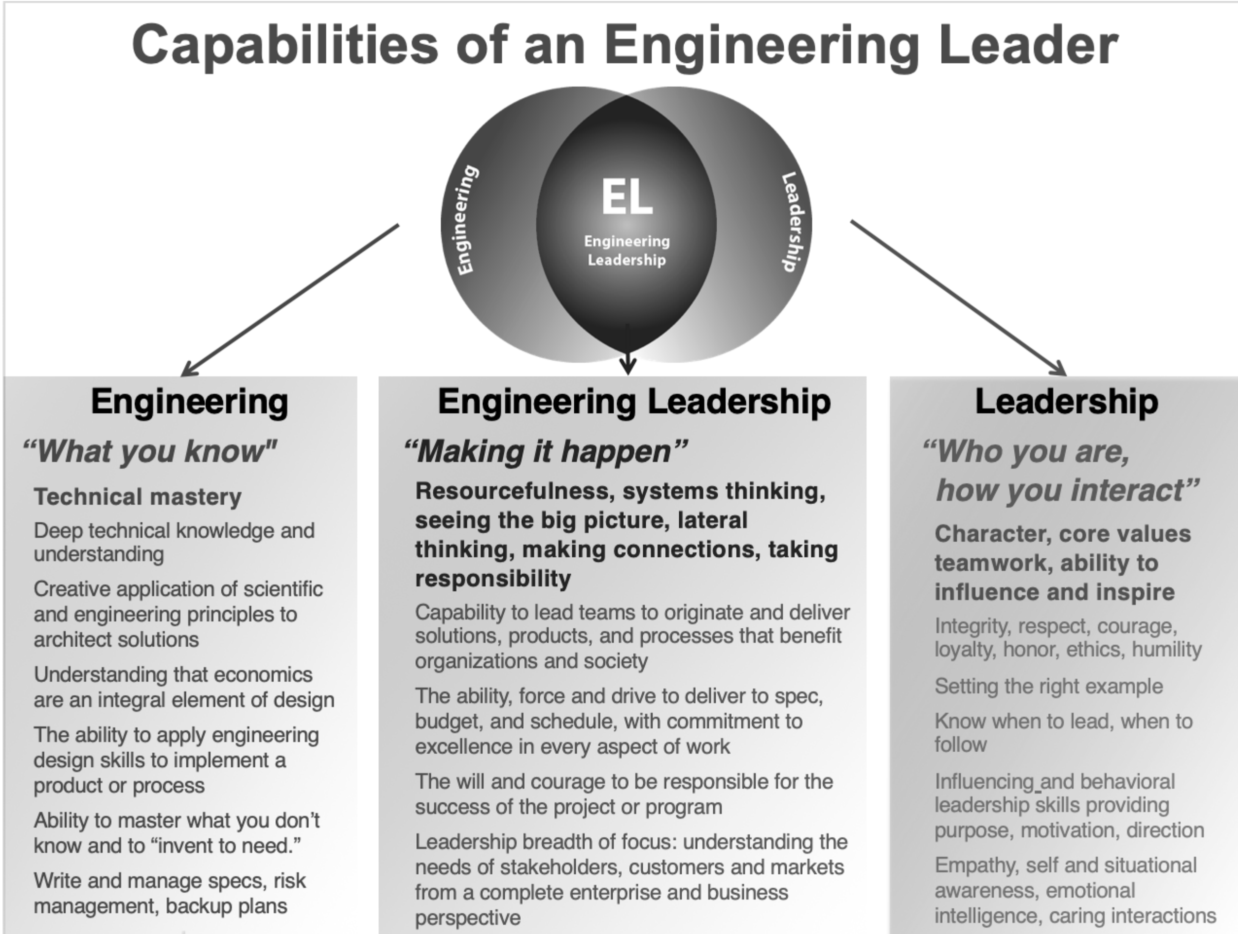
In 2018, the US engineering accreditation body ABET (Accreditation Board for Engineering and Technology) approved changes to its student learning outcomes to include “an ability to function effectively on a team whose members together provide leadership…” (ABET 2018, p.6). Most large engineering leadership programs define their own specific student learning outcomes to operationalize this broader outcome in a context-relevant way. A 2015 study of engineering leadership programs found common themes in the overarching program competencies, including managing complex tasks, responsibility, working with others, self-awareness, personal skills and active engagement (Paul & Cowe Falls, 2015).

Status of engineering leadership education programs. In the last 10-15 years, explicit engineering leadership educational initiatives have grown in number and scope. Many champions and observers cite the influential 2004 National Academy of Engineering report “The Engineer of 2020” as having initiated the call for engineering leadership education (Graham, Crawley, & Mendelsohn, 2009; National Academy of Engineering, 2013). Funding has helped, too. Engineering entrepreneur and philanthropist, Bernie Gordon, established several multi-million-dollar endowments which launched programs, centers and institutes at multiple US sites from MIT to Northeastern to UC San Diego. A 2009 study on the global emergence of engineering leadership education (Graham et al., 2009) looked at case studies of both endowed programs (MIT) as well as organically emerging engineering leadership institutes at Pennsylvania State University, Iowa State University, and Monash University. A community of engineering leadership institutes was formalized as the Community of Practice on Leadership Education for the Twenty-First Century Engineer (COMPLETE). COMPLETE provides a forum for program directors to discuss strategic issues from curriculum, to funding, to navigating university politics. Today, more than fifty higher education institutions in North America host engineering leadership programs (Palmer, Birchler, Narusis, Kowalchuk, & DeRuntz, 2016), supported by new networks, such as the National Initiative for Capacity Building and Knowledge Creation for Engineering Leadership (NICKEL) in Canada and an institutional home in the American Society for Engineering Education’s Engineering Leadership Development Division (LEAD).

Approaches to leadership. With such an upsurge in programming and research, questions of boundaries, identity and definition were not far behind. Comparative analysis of fourteen engineering leadership programs identified a tension between definitions of engineering leadership that emphasize position, and others that emphasize process (Klassen, Reeve, Rottmann, & Sacks, 2016). Many attempts to define engineering leadership have resulted in lists of effective leadership skills and traits informed by surveys and consultations with engineers in industry (Paul & Cowe Falls, 2015). The COMPLETE group has discussed engineering leadership definitions on numerous occasions; the latest representation is shown in Figure 8.1 (S. Pitts & J. Schindall, personal communication, 2019):

Insert figure 8.1 about here

Figure 8.1 Capabilities of an Engineering Leader



Adapted from Pitts & Schindall, 2019

Another approach to understanding the distinctiveness of engineering leadership emerged from a study examining how professional engineers understand and enact leadership. A grounded theory approach led to the development of three distinct orientations to engineering leadership: technical mastery, collaborative optimization, and organizational innovation (Rottmann, Sacks, & Reeve, 2015). Interestingly, this research revealed wide-spread resistance to the word "leadership" by engineers, including those identified as star performers – leaders - by their managers and HR units. Many participants viewed engineering as a "service profession" driven by collaborative, technical problem solving, while viewing leadership as a positional application of authority. Several engineering leadership programs have integrated these findings into undergraduate engineering education to help students expand their somewhat traditional notions of leadership in ways that complement their deeply held professional identities. Still, engineers' resistance to accepting a leadership identity remains a challenge for educational programs seeking to develop the leadership capacity of engineers (Schell & Hughes, 2017).

Student Leadership Education and Development

Given some engineers' discomfort with the term leadership, the range of definitions, and the emergence of locally developed programs, the diversity of engineering leadership offerings is unsurprising. From undergraduate to graduate students, theoretical to practical, for-credit or not-for-credit, engineering leadership programs offer modules, courses, certificates, minors and degrees. Table 8.1 below summarizes seven key analytical dimensions along which engineering leadership programs differ (Klassen et al., 2016).

Insert Table 8.1 about here

Table 8.1: Dimensions of Engineering Leadership

Dimension	Range of the spectrum
1) End Goal	Economic impact to social impact
2) Application of Leadership Learning	Theory to practice
3) Scale of Leadership Action	Individual to organizational
4) Leadership Emphasis	Process to position
5) Participant Selection	Inclusive to exclusive
6) Compulsoriness	Core/mandatory to optional/self-selection
7) Curricular Integration	Integrated/embedded to separate

After assessing fourteen major programs along each of these seven dimensions, the authors identified three different clusters of program types that illustrate the variety present:

- Technical integration programs emphasize individual leadership for economic growth and deliver learning through integration with technical engineering learning.
- Social impact programs emphasize organizational leadership for societal impact and deliver learning through workshops, service learning and elective courses.
- Core curriculum approaches integrate leadership and teamwork into mandatory courses taken by all engineering students in a program.

Pedagogies. At a pedagogical level, the expansion of team design projects has created a major opportunity to integrate teamwork learning, feedback and development into mandatory, project-based courses. Design courses traditionally occurred as a “capstone” in students’ final year to integrate technical knowledge through authentic applications. Recently, design courses have been added in multiple years and have become the primary site for teaching professional skills.

Some work in this area has focused on developing effective team members through individualized feedback (Sheridan, Evans, & Reeve, 2015). Feedback provides students with opportunities to refine their interpersonal leadership practices, leading to greater team effectiveness. The extremely large class size (300-1000 students) in many core engineering courses means that applying these teaching practices at scale often requires additional resources or the use of on-line systems to mediate individualized feedback in a timely manner such as *TeamWorks Ed* (Teamworks Ed, 2019), CATME (CATME SMARTER Teamwork, 2018), and ITP Metrics (ITP Metrics, 2016). These systems are most impactful when integrated with instruction on how to provide and improve from feedback (Sheridan, 2018).

The role of clubs and organizations. Many engineering students participate actively in student clubs and organizations. There are dozens of student design competitions, social identity groups such as Women in Science and Engineering (WISE) and the National Society of Black Engineers (NSBE), and social impact organizations such as Engineers Without Borders (EWB). These activities contribute to leadership skill and identity development in their own right (Rottmann, Sacks, Klassen, & Reeve, 2016), and many engineering leadership programs have developed support systems that explicitly teach leadership in the context of these extra-curricular activities. A long-standing catalyst for leadership and professional development in engineering education has involved internships and co-op placements. To date, online course modules and the use of journals for reflection have been used to support leadership learning in workplace contexts.

Models and theories. At a content level, the underlying principle shaping selection of knowledge for teaching is "what works" – reflecting the engineering ethos of pragmatic tinkering. Recent curriculum analysis reveals that many programs emphasize leadership at levels of self and team, drawing on notions of authentic and emotionally intelligent leadership (Donald & Klassen, 2018) [For resources see the appendix in this issue]. There is widespread use of the "social styles" model for unpacking different leadership and work style preferences (Bolton & Bolton, 2009). This model can help unpack stereotypes of engineers as antisocial or "analytical".

The importance of ethics. Engineers' commitment to public safety is a central part of their social contract with society, making ethics a key feature of engineering leadership education. An important emerging aspect of ethics in engineering involves the integration of equity-infused ethical dilemmas impacting engineers from marginalized groups as they enter masculine cultures of engineering in both the academy and workplaces (Cech & Sherick, 2015; Riley & Lambrinidou, 2015). It is crucial for engineering students to unpack and reflect on their possible roles as bystanders, targets, or even perpetrators of various forms of harassment, something we have begun to do using deeply contextualized case studies based on the experiences of demographically diverse engineers who encountered ethically ambiguous situations at work (Rottmann, Reeve, Saks & Klassen, 2018). Unfortunately, this work can be challenging given engineers' implicit reliance on epistemic neutrality (Cech, 2014). Teaching ethics and, in some jurisdictions, equity is mandated through accreditation, but is often treated as a "box to tick" rather than an opportunity for deeper engagement in complex human dilemmas at the core of engineering work. Fortunately, several engineering programs have sought to reclaim ethics in the context of leadership education, linking it to values, team development, and organizational leadership.

Challenges for Leadership Development

Today, engineering leadership education faces three distinct and interconnected challenges: curricular positioning and scale, faculty status, and disrupting marginalization.

Curricular positioning and scale. Analysis of the organizational dimensions of engineering programs shows most leadership courses and programs are small and elective, meaning that only a few self-selecting students are accessing them. They sit on the periphery of the undergraduate engineering curriculum, where they might count towards accreditation breadth requirements, but they would not be considered part of the core curriculum. This reflects a wider legitimacy challenge for engineering leadership and the faculty members who teach it. In order to integrate leadership education further into the core curriculum for all students, more faculty need to see the need for it, and have the necessary skill set to deliver it.

Faculty status. A persistent theme running through this chapter is the importance of leadership 'champions' who have the will and ability to convince their academic colleagues that leadership education has a place within the curriculum and the profession. So, who are these champions? An analysis of engineering leadership papers published by the American Society of Engineering Education shows that a disproportionate number of lead authors have experience in industry (Schell & Kauffmann, 2016). These industry-experienced faculty often have legitimacy in the eyes of students (as "real" engineers with "real world" experience), but by tying credibility to industry affiliation, we run the risk of redefining leadership education as corporate career preparation, thereby narrowing the range of potential learning. Additionally, while industry affiliation may afford engineering leadership educators with credibility in the eyes of students, the applied nature of their experience can undermine credibility in the eyes of research-oriented colleagues, leaving leadership education at the periphery of the engineering curriculum.

Disrupting marginalization. Finally, if engineering leadership is to reach all students, then it needs to do so with a critically aware pedagogy that recognizes major power differences and historical marginalization of many social groups within engineering. Deeper cultural and structural changes are required for leadership and engineering to reflect the experiences of all students, not just those who fit the image of historically dominant groups. Earlier in the chapter, we presented ethics and equity case studies as one entry point for disrupting marginalization, but additional complementary strategies are needed to shift the engineering education culture. Prime among these is a deliberate disruption of dualistic thinking separating social and technical aspects of the profession (Faulkner, 2000). To the extent that we can integrate socio-technical thinking into the core engineering curriculum, we will be making space, not only for ethics and equity, but also for leadership in engineering education.

Opportunities for Leadership Development

Integration with engineering curriculum at scale. Future prospects for the evolution of engineering leadership lie in boosting legitimacy for leadership and building the capacity of faculty to teach it at scale, so that the full range of students can access and see themselves reflected in leadership education.

Engineering faculty members have traditionally established legitimacy in academic institutions through government grants, technical research, and publication in high impact journals. More recently, due in part to changing accreditation requirements, engineering leadership educators and researchers have begun to be recognized through a wider range of achievements. In particular, funding from external donors, industry partners and forward-looking deans and provosts have signalled to more traditional engineering academics that leadership is valued by important stakeholders and ought to be integrated into the core engineering curriculum. Research on the topic is also growing, and the creation of a division within an existing discipline-based educational research organization such as ASEE has enhanced the profile and credibility of engineering leadership development research, and partnerships with core faculty members have provided local boosts at individual institutions.

Significant progress has been made, not only at the level of senior administrators and researchers, but also in engineering education classrooms. Engineering educators committed to supporting the interpersonal and technical development of their students have begun to develop pedagogy, assessment and feedback to help engineering students in very large classes learn about how to be an effective team member and leader (Sheridan, 2018). Beyond tools and techniques is the relational approach to partnering with faculty members, particularly those who do not see themselves as leadership experts. A recent conference in August 2018 hosted by the NICKEL community (in Canada) explicitly focused on the nexus of engineering leadership and engineering design, showcasing approaches for integrating leadership learning into engineering design contexts: from values awareness in influencing both team process and engineering products, to ethical case studies.

Engineering offers useful lessons for other disciplines seeking to make leadership a vibrant and visible component of education: On the one hand, champions have worked to carve out a distinct space for its existence as a field in its own right, through gatherings, networks and communities of practice both nationally and internationally. On the other hand, for engineering leadership to thrive, it needs to connect to other aspects of the engineering canon and be integrated into existing organizational structures and practices of the profession.

Conclusion

Engineering education has shifted over the past century from practice to theory—with two related consequences—increased institutional status in academic settings, and the relegation of professional skill development—including leadership—to the workplace. More recently, industry and professional bodies have re-asserted the importance of "non-technical" skills, which has created openings for a leadership resurgence. This chapter reports on the range of leadership programs, institutes and research that have begun to thrive over the last decade and a half across North America. Compared to other disciplines—such as management—in which leadership development has historically been an explicit learning outcome—engineering provides leadership educators with a case of overcoming professional resistance to leadership. In short, this chapter illustrates how engineering educators can incrementally shift leadership education from the periphery to the core of an intensely technical curriculum through a combination of evidence-based educational practices and relationship building. The case for infusing leadership development into engineering education is best delivered when supported by empirical research on how engineers lead and through partnerships between faculty members and industry leaders.

Sample of Engineering Leadership Education Practices

University of Toronto – Troost Institute for Leadership Education in Engineering (Troost ILead): Troost ILead emerged from a small co-curricular program started in 2002 to a thriving institute combining curricular and co-curricular programing, engineering leadership research and outreach to a community of industry and academic partners. It offers fifteen elective courses on engineering leadership to graduate and undergraduate students, integrates leadership learning into over twenty-five courses, provides a diverse array of co-curricular programs from professional development to social innovation, and tailored programs for PhD students and post-docs looking to transition to industry. The Institute is supported by strong industry partnerships that fund social science research, matched in many cases by funding from the dean's office. The Institute is led by an endowed-chair Director and has two assistant professors of engineering leadership among its staff. Troost ILead is part of the new Institute for Studies in Transdisciplinary Engineering Education and Practice (ISTEP) at the University of Toronto. (http://ilead.engineering.utoronto.ca/).

University of British Colombia (UBC) – Masters of Engineering Leadership (MEL) degrees: UBC's Master of Engineering Leadership (MEL) is a suite of professional master's degrees connecting engineering leadership with specific industry knowledge and experience. Degrees range in focus from Clean Energy Engineering to High Performance Buildings to Dependable Software Systems, representing a break from the traditional engineering disciplines. The degrees were initiated from a top-down push from the dean and provost to increase revenues. The curriculum is jointly developed by engineering academics and professors from the business school, and thus the leadership courses are business oriented. A popular option taken up by students is an accelerated venture 'boot camp' offered in the summer. MEL is operated by a separate office of faculty members and administrative staff with strong support from the dean's office. (https://apscpp.ubc.ca/programs/mel/)

University of Texas at El-Paso (UTEP) – Bachelors of Engineering Leadership (E-LEAD)
UTEP's Bachelor of Engineering Leadership (E-LEAD for short) is the first formal undergraduate degree in engineering leadership in the US. It is housed in a unique department that was launched to be able to hire its own faculty members: The Department of Engineering Education and Leadership. Students in the program take one explicit E-LEAD course as a small cohort each semester for their four-year degree, and integrate with other engineering students for the rest of their courses. E-LEAD's approach to leadership education tightly integrates it with design and entrepreneurship, teaching leadership in the context of design projects and alongside key business concepts. (http://e-lead.utep.edu/)

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Biographies

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Annie Simpson is the Associate Director of Troost ILead. She has been designing, overseeing and delivering leadership education for engineers since 2007, drawing on a background in Adult Education, Psychology and work as a counsellor and restorative justice facilitator.