Diversity of engineering leadership program design

John R. Donald1 | Marnie V. Jamieson2

1University of Guelph, Canada
2University of Alberta, Canada

Abstract
This article outlines the diversity of engineering leadership programs by comparing origin stories, definitions, program structure, instructional strategies, research, and program evaluation approaches of seven North American engineering leadership programs.

INTRODUCTION

Challenging and complex issues facing society, as reflected in the UN Sustainable Development Goals and the NAE Grand Challenges for Engineering, require engineers to develop integrated professional, contextual, technical, cognitive, and metacognitive skills. The resolution of high profile and high stakes issues, such as climate change and engineering risk management, require technically trained engineers to identify as part of a “leadership profession” with the professional competence to examine the broader social impact of their work (Jamieson et al., 2021). Engineering education has been responding to this challenge for the past 25 years using various approaches, including integrating engineering leadership programming. National accreditation boards in the United States (ABET, 2019) and Canada (CEAB, 2020) capture engineering leadership as an important outcome for engineering programs.

There is no single way to implement a relevant engineering leadership curriculum into engineering undergraduate and graduate programs. Formal and informal programs have typically grown in response to broader industrial and societal needs. This article provides insight into the diversity of engineering leadership (EL) programs in universities and colleges across the United States and Canada. We review seven EL programs where program implementation has progressed to the point of explicitly identifying the formal development of engineering leadership competencies and has grown beyond a single champion. These EL programs can be found in Part 3. These EL programs generally have a named
EL certificate program, degree, centre, teaching team, and/or formal curricular integration and vary in scope of implementation.

**ENGINEERING LEADERSHIP PROGRAMS**

Discipline-based leadership education to prepare graduates for professional practice is relatively new to higher education in North America (Sowcik & Komives, 2020). While the earliest EL programs were established in the late 1980s, it was not until the early 2000s when they began to appear more prominently across North America (Graham et al., 2009; Macza, 2008; Peterson et al., 2002). Since then, scholarly attention to engineering leadership has grown, as has the number of engineering leadership development programs at institutions across North America. Klassen et al. (2016) identified more than 50 EL programs, while Paul and Cowe Falls (2015) and Palmer et al. (2016) reported 30–40 in their initial screening. Graham et al. (2009) conducted a cross-case analysis of 40 EL programs and found passionate champions operating on a relatively small budget initiated most programs. The visionary champion development model is supported by Klassen et al.’s (2016) observation that engineering leadership programs tend to take root and grow outside of the formal technical engineering curriculum. Examples include co-curricular programs, small cohort-based programs, and the integration of EL modules in team-based design courses. Professors of practice and those with industry experience tend to be involved in teaching and championing EL programs (Sowcik & Komives, 2020). As growing numbers of faculty, staff, and students appreciate the value of EL, programs have grown in number, expanded their scope, and become more formalized. Our literature review examines four key features of EL programs, including program goals and structure, engineering leadership definitions, instructional strategies, and EL research and program evaluation.

**Program goals and structure**

As programs became more formalized, directors began to articulate program goals, vision, and mission statements. An examination of 11 EL programs by (Paul & Cowe Falls, 2015) produced ten broad themes including the ability to do innovative and complex technical design work, understanding social impact and service, and enhanced metacognitive and professional competencies. Klassen et al. (2016) identified seven dimensions of engineering leadership programs, providing insight into how 14 programs conceptualize engineering leadership. They found that most conceptualized leadership as a process, prioritizing practice over theory, and teams over individual or organizational levels of analysis. Graham et al. (2009) reviewed 40 EL programs and noted a distinction between those driven by organizational or economic goals and those driven by service or social impact goals. EL programs have different goals and a diversity of institutional structures, including co-curricular offerings, undergraduate minors, and fully accredited degree programs at the undergraduate and graduate levels (Donald & Klassen, 2018; Graham et al., 2009; Klassen et al., 2016). In many cases, programmatic structures reflect the priorities and definitions of engineering leadership held by program directors and key funders. EL programming can be part of a specific degree program or a larger institutional transdisciplinary entity dedicated to engineering leadership research and development opportunities. Most programs target the development of leadership skills in the context of engineering work and practice using a range of delivery scales from elective, application-based cohort programs to large-scale curricular integration reaching all engineering students.
Defining engineering leadership

Engineering leadership definitions are useful for program clarity and communication, help EL educators distinguish their programs from those offered by business schools and provide a rationale for including leadership development in engineering. For example, Paul et al. (2018) note that “through engineering leadership, individuals and groups implement transformative change and innovation to positively influence technologies, organizations, communities, society, and the world at large” (p. 10). Key distinguishing features of engineering leadership include the technical and contextual nature of the discipline (Sowcik & Komives, 2020) and the applied nature of the engineering leadership curriculum to realize engineered designs in the context of societal systems and sustainability.

In their critical review of the engineering leadership literature, Schell and Kauffmann (2016) assembled leadership definitions from several engineering professional societies and over 20 EL programs finding a lack of EL definition consensus in both professional and academic settings. Notwithstanding, they do note areas of broad agreement, specifically: engineering competence, problem-solving and decision-making, collaboration and influencing others, visioning, setting direction, ethics, and the ability to deliver results. Interestingly, Rottmann et al. (2015) note engineers do not identify completely with conventional notions of leadership, such as that set out by Northouse (2019): “leadership is a process whereby an individual influences a group of individuals to achieve a common goal” (p. 5).

EL definitions tend to focus on conventional leadership skills and traits contextualized to engineering practice. For example, Farr et al. (1997) present a model of nine engineering leadership characteristics that include elements such as team building, being a master of change, and ethics and courage. Rottmann et al. (2015) interviewed practicing engineers who identified with engineering leadership as characterized by three orientations grounded in engineers’ professional practice: technical mastery, collaborative optimization, and organizational innovation. After examining EL definitions for common themes and surveying students and alumni, Paul et al. (2018) proposed, “Engineering leadership is an approach that influences others to effectively collaborate and solve problems” (p. 10). Four themes emerged from their analysis: innovation and technology, independent learning, experiential learning, and system thinking. After studying four emergent models of engineering leadership from programs responding to calls for developing 21st-century engineering behaviours and competencies, Kendall et al. (2018) found four emergent themes: technical mastery, teamwork, contextual awareness, and effectual behaviour. Jamieson and Donald (2020) build on the importance of self-awareness and regulation as a developmental starting point for engineering leadership education, noting, “leadership starts with a need to understand and manage your own knowledge and skills, and then grow to be able to manage at larger scales of influence” (p. 4).

Though no one definition fits, the emergent EL themes have several common threads and align with other graduate attribute-based thematic frameworks, such as that proposed by Jamieson and Shaw (2019), which identifies technical, professional, socio-contextual, and metacognitive knowledge and skill development, as thematic categories. A synthesis of the above EL definitions and themes is captured in this generalized framework (Figure 1).

Instructional strategies

Just as engineering leadership programs can vary in structure, strategies for delivering engineering leadership content can vary. Klassen and Donald (2018) utilised the Lattuca and Stark (2011) academic plan model to analyse pedagogical elements of the EL cur-
riculum and found a wide variety of instructional approaches and resources. EL programs blended traditional and experiential education strategies such as lectures, team projects, group discussions, industry visits, guest lectures, workshops, and community-building activities. Reference materials were similarly varied, drawing on leadership theories, professional magazines, case studies, videos, and online resources. Student assessments relied on self and peer evaluation, summative and formative project evaluation, exams, presentations, reflection essays, and class participation. Interestingly, while program structure and focus tended to differ by nationality, instructional strategies were similarly diverse in the United States and Canada.

Notwithstanding the wide variety of observed instructional strategies, several common pedagogical approaches are used in EL programming (Kendall et al., 2018). These include a preference for experiential education such as team-based leadership or design projects; case study analysis; a grounding in personal leadership development principles; traits and characteristics (personality), behavioural (conflict management), and process (leadership) type inventories; reflective practice, student peer and team assessments; student presentations; industry guest speakers or workshops; and strong linkages to EL skills as a driver of career success. The prominence of these instructional strategies may be reflective of the practical nature of both engineering and leadership.

**EL research and program evaluation**

While the primary focus of EL programming is student development, interdisciplinary engineering leadership research teams have begun to document best practices, compare EL programming across institutional contexts (Kendall et al., 2018), study EL workplace practices, and develop evidence-based resources (Rottmann et al., 2015). The results enhance the understanding of EL programming dimensions, delivery, and program impact. This growing capacity has improved the ability to articulate the need for leadership education in engineering and formulate mechanisms for evaluating existing program effectiveness. To this end, we now turn to our analysis of the seven case studies we reviewed.
PROGRAMMATIC DIVERSITY – CASE STUDY

Part 3 includes seven case studies of EL programs representing a diversity of programmatic structures and institutional types. The seven case studies in this collection feature formalized engineering leadership programs that respond to the call for better alignment with professional practice. Case study authors were encouraged to respond to the following prompts corresponding with sourcebook chapters: origin story; program description; unique features; EL definitions; instructional strategies; teamwork; diversity, equity and inclusion (DEI) efforts; research; and assessment. We briefly discuss programmatic diversity across institutional settings in relation to these dimensions. Table 1 summarizes our analysis.

Origin story

All seven programs respond to the call for better alignment of engineering education with professional practice and specifically highlight communication, teamwork, innovation, social and economic impact. Most were initiated by a faculty champion or philanthropic leader with industry ties. Some began by establishing elective courses, while others began with co-curricular offerings. Several large-scale programs began with a series of courses that grew into minors, certificates, or full degree programs. EL program activities started small with significant program growth over 15–20 years, often leading to establishing a centre for EL activities.

Program description and unique features

Program structures included application-based co-curricular cohorts (JMU, MIT, UC San Diego), multiple integrated offerings (University of Toronto), and accredited certificates or degree programs (Penn State, The Citadel, UTEP). UTEP established a new precedent with EL programming as an accredited undergraduate degree program. All programs are housed in engineering schools, with participation open to students across engineering disciplines, often at both the undergraduate and graduate levels. Unique program features tended to reflect the climate and character of their host institution. For instance, the Citadel’s project management program reflected its formalized institutional structure as a military college, while programs with entrepreneurial or research programs tended to emerge from smaller start-ups housed in large, research-intensive universities. All programs recognized the need to supplement technical mastery with socio-contextual and professional skills, with most explicitly addressing economic realities and engineers’ professional responsibility for social impact.

Engineering leadership definitions

Most programs identified the intersection of technical competence and leadership as a productive way to conceptualize engineers’ professional responsibilities. While some directors developed frameworks to drive their programs, few rooted their work in a clear theory or definition of engineering leadership. Rather, most identified key priorities and program elements as a framework, often foregrounding leadership skills and traits, teams, and organizations, as relevant levels of analysis. Programs diverge in their EL priori-
| Location Institution Type Program Name | The Citadel | James Madison U | MIT | Penn State | UC-San Diego | UT-El Paso | U of Toronto |
|----------------------------------------|------------|----------------|-----|------------|--------------|------------|-------------|
| Institution Type                      | Small, Public, Military Engineering Leadership and Program Management (ELPM) | Madison Engineering Leadership Development (MELD) | Cambridge, MA Small, Private, Research Gordon-MIT Engineering Leadership Program (GEL) | Old Main, PA Large, Public, Research Engineering Leadership Development (ELD) Program | San Diego, CA Large, Public, Research Engineering Leadership Development Centre | El Paso, TX | Toronto, ON |
| Name                                  | Charleston, SC | Harrisonburg, VA | Cambridge, MA | Old Main, PA | San Diego, CA | El Paso, TX | Toronto, ON |
| Unit                                  | Department of Engineering Leadership and Program Management | Department of Engineering | School of Engineering | College of Engineering | Jacobs School of Engineering | Department of Engineering Leadership Development Centre | Institute for Studies in Transdisciplinary Engineering Education & Leadership |
| Program Type                          | Master of Science and Project Management; Graduate certificate | Integrated curricular & co-curricular blend (Cohort based) | Undergraduate Minor; Graduate Degree or Certificate | Co-curricular (Cohort based) | B.S. in Engineering Innovation & Leadership (Accredited) | B.S. in Engineering Innovation & Leadership (Accredited) | |
| Program Reach                         | 51 Grad | ≤24 U/G | 170 U/G | 200 U/G | 35–50 U/G & Grad | 100 U/G | |
| Admission process                     | Application | Application Elective (U/G) | Application | Elective (U/G); Application (G) | Application Declare as major | Application | Credit Courses (440 U/G; 226 G) Co-curricular (973 U/G, 685 G) |
| Program Duration                      | 1 year - 10 credits Leadership through technical management | 1 year | 2 years | 6 credits | 1 year | 4 years | <1 year in general |
| Program Focus/ Vision                 | Develop skills and attitudes to become effective, ethical, and empathic leaders | Develop technical leaders with skills, values, and attitudes to solve engineering problems. | Close the gap between practice requirements and engineering education | Develop effective engineering leaders to create products to benefit society – on time, on budget | Engineering Innovation and Leadership within an entrepreneurial mindset | Engineers leading change to build a better world |
| Founded Program Catalyst              | 2006 Industry Demands | 2014 Social Action Vision | 2007 Donation – Philanthropic Vision Engineering Dean’s Graduate Student Advisory Group on Leadership Development | 1995 Career Impact and Preparation International virtual teaming experience | 2004 Dean’s Vision | 2002 Internal Champion |
| Unique Features                       | PMI Global Accreditation Centre PMI Talent Triangle | Leadership practicum. Blend theory and practice with personal exploration and mentorship | Leadership practicum. Dean’s Graduate Student Advisory Group on Leadership Development | International virtual teaming experience | ABET Accredited B.S. in Engineering Innovation & Leadership | Blends programming research & outreach; extensive curricular integration |
| Key Instructional strategies          | PMBOK - leadership in project management | Theory/practice, mentorship | Leadership labs, personal reflection, theory/practice | PBL, with root cause analysis and sustainability | Skill building towards developing EL characteristics | Theory/practice, design, reflection | Leadership labs, personal reflection, community building |

(Continues)
ties, with some favouring technical applications like project management or innovative design and others favouring personal development in the form of self-awareness. Programs tended to converge on effective collaboration, the importance of communicating one’s vision, and contribution to the broader public interest.

### Instructional strategies, teamwork, and DEI

Instructional strategies varied as much within each program as between programs. Faculty and staff adopted case studies, leadership labs, guest lectures, workshops, large and small group discussions, team projects, reflective journaling, leadership interviews, and integration with PBL and design projects. All programs embraced experiential learning, team interaction, and personal development. There was significant variation in program development ranging from MIT where educational design and subject matter experts were employed to James Madison University where undergraduate elective sequence was leveraged.

When it came to ABET and CEAB accreditation requirements, teamwork stood out as a consistently well-integrated EL program element. The Citadel identified the importance of followership while other programs addressed the need to interact with teammates through interpersonal skill-building activities. In contrast to the seamless integration of teamwork, DEI remains on the periphery of most EL programs. Three program directors identified DEI as an explicit course topic, while others spoke about it more implicitly as a value without distinct program elements. In the University of Toronto case, there was specific reference to research-based teamwork and DEI resources delivered through course integration.
Research and program evaluation

Consistent with our literature review findings, few programs reported theoretically framed program evaluation processes, with Penn State standing out as an exception. Rather, most evaluated program effectiveness through student feedback surveys and follow-up testimonials by alumni. UTEP, an ABET-accredited program, was in a unique position to receive and integrate external feedback on all program elements into EL offerings. Most programs indicated intentional improvement efforts, engaging advisory boards, students, experts, and program instructors; however, because of the integrated nature of much EL programming, discrete EL program evaluation continues to be a challenge.

In addition to program evaluation, there is an increasing appetite to engage in EL research. Along with other EL institutions, MIT, Penn State, UTEP and University of Toronto regularly engage in EL research and have begun to admit graduate students with an EL focus.

CONCLUSIONS

Leadership education enables engineering graduates to address complex sociotechnical problems they will inevitably face in their professional practice. The EL programs we review in this chapter reflect a diversity of programmatic goals, structures, priorities, and frameworks reflective of the variety of professional contexts in which students will work throughout their careers. Programmatic diversity aside, there is general agreement that EL programming should equip engineering students with a core set of skills, knowledge, and attitudes that will enable the effective utilization of their technical training and engage in the leadership, management, and implementation of technology for the betterment of society. As the number of engineering leadership programs grows, so too does the need for research and practice communities in this emerging field.

REFERENCES

ABET. (2019). *Criteria for accrediting engineering programs: Effective for reviews during the 2020–2021 accreditation cycle*. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2020-2021/

CEAB. (2020). *2020 accreditation criteria and procedures*. Engineers Canada.

Donald, J., & Klassen, M. (2018). Comparing engineering leadership curricula in Canada and the United States: The role of external and internal influences. *2018 IEEE Frontiers in Education Conference (FIE)*, 1–9. https://doi.org/10.1109/FIE.2018.8658444

Farr, J. V., Walesh, S. G., & Forsythe, G. B. (1997). Leadership development for engineering managers. *Journal of Management in Engineering, 13*(4), 38–41. https://doi.org/10.1061/(Asce)0742-597x(1997)13:4(38)

Graham, R., Crawley, E., & Mendelsohn, B. R. (2009). Engineering leadership education: A snapshot review of international good practice. Bernard M. Gordon MIT Engineering Leadership Program.

Jamieson, M., & Donald, J. (2020). Building the engineering mindset: Developing leadership and management competencies in the engineering curriculum. *Proceedings of the Canadian Engineering Education Association (CEEA)*. https://doi.org/10.24908/pceea.v10.14129

Jamieson, M., & Shaw, J. (2019, June). A continual improvement process for teaching leadership and innovation within a community of practice. *2019 ASEE Annual Conference & Exposition Proceedings*.

Jamieson, M. V., Lefsrud, L. M., Sattari, F., & Donald, J. R. (2021). Sustainable leadership and management of complex engineering systems: A team based structured case study approach. *Education for Chemical Engineers, 35*, 37–46. https://doi.org/10.1016/j.ece.2020.11.008

Kendall, M. R., Chachra, D., Roach, K., Tilley, E., & Gipson, K. (2018). Convergent approaches for developing engineering leadership in undergraduates. *2018 ASEE Annual Conference & Exposition Proceedings*, 30225.

Klassen, M., & Donald, J. (2018). Using an academic plan model to analyze Canadian engineering leadership curriculum. *Proceedings of the Canadian Engineering Education Association (CEEA)*. https://doi.org/10.24908/pceea.v10.12981
Klassen, M., Reeve, D., Rottmann, C., Sacks, R., Simpson, A., & Huynh, A. (2016, June 26–29). Charting the landscape of engineering leadership education in North American universities. *2016 ASEE Annual Conference & Exposition*, New Orleans, LA, United States. https://doi.org/10.18260/p.26486

Lattuca, L. R., & Stark, J. S. (2011). *Shaping the college curriculum: Academic plans in context*. Wiley.

Macza, M. (2008). A Canadian perspective of the history of process safety management legislation. *8th International Symposium Programmable Electronic System in Safety-Related Applications*, 22.

Northouse, P. G. (2019). *Leadership: Theory and practice* (8th ed.). SAGE.

Palmer, J., Birchler, K., Narusis, J., Kowalchuk, R., & DeRuntz, B. (2016, June 26–29). LEADing the way: A review of engineering leadership development programs. *2016 ASEE Annual Conference & Exposition*, New Orleans, LA, United States. https://doi.org/10.18260/p.25525

Paul, R., & Cowe Falls, L. (2015). Engineering leadership education: A review of best practices. *2015 ASEE Annual Conference and Exposition Proceedings*, 26.634.1-26.634.11. https://doi.org/10.18260/p.23972

Paul, R., Sen, A., & Wyatt, E. (2018). What is engineering leadership? A proposed definition. *ASEE Conference Proceedings*, 14.

Peterson, W. A., Keating, C., Kauffmann, P., & Unal, R. (2002). Engineering management—The minor of choice. *2002 Annual Conference Proceedings*, 7.486.1-7.486.4.

Rottmann, C., Sacks, R., & Reeve, D. (2015). Engineering leadership: Grounding leadership theory in engineers’ professional identities. *Leadership, 11*(3), 351–373. https://doi.org/10.1177/1742715015543581

Schell, W. J., & Kauffmann, P. J. (2016). Understanding engineering leadership: A critical review of the literature. *Proceedings of the American Society for Engineering Management 2016 International Annual Conference*, 11.

Sowcik, M., & Komives, S. R. (2020). Emerging themes in disciplinary based leadership education. In M. Sowcik & S. R. Komives (Eds.). *New directions in student leadership #165. How academic disciplines approach leadership development* (pp. 162–181). Wiley. https://doi.org/10.1002/yd.20377

**AUTHOR BIOGRAPHIES**

**John R. Donald** is an associate professor at the University of Guelph with over 25 years of leadership experience in post-secondary education and engineering consulting. John is a past president (2017–18) and fellow (2020) of the Canadian Engineering Education Association (CEEA), and founder of the Guelph Engineering Leadership Program. His current research focuses on engineering leadership and development of professional skills in the engineering design curriculum.

**Marnie V. Jamieson** is a teaching professor at the University of Alberta. She is currently the William Magee Chair in chemical process design and leads the process design and first year design teaching teams. Her current research focuses on engineering design and leadership, the engineering graduate attributes and their intersection with sustainability, learning culture, and continuous course and program improvement.

**How to cite this article:** Donald, J. R., & Jamieson, M. V. (2022). Diversity of engineering leadership program design. In M. R. Kendall & C. Rottmann (Eds.). *New Directions for Student Leadership: No. 173. Student leadership development in engineering* (pp. 83–91). Wiley. https://doi.org/10.1002/yd.20482