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Charting the Landscape of Engineering Leadership Education in North American Universities

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Charting the landscape of engineering leadership education in North American universities

Globalization and increased economic competition are putting increasing pressure on engineering companies to produce value. At the same time, competition in the higher education system, linked to global rankings metrics, is putting pressure on engineering programs to differentiate. These two pressures together have created the impetus for the growth of initiatives in engineering leadership within universities, which have attracted funding from private donors, companies, and faculty budgets.

In 2009, MIT commissioned a study to look at international best practice in engineering leadership education. The report noted the relative newness of the field, and reported on the growing number of independent initiatives[1]. Since then, changes to the field have been substantial. Existing programs have grown and evolved, and there are a significant number of new entrants to the field, including a Bachelor's Degree in Engineering Leadership[2].

There has also been development in networks dedicated to sharing good practice in engineering leadership education among universities[3,4]. One of the benefits of these networks is the increasing availability of information on programs, strategies and results. However, at present most of this information is anecdotal, casual, and structured around the perspectives of the authors, who tend to be architects of their own particular programs.

The field is loosely bound together around the common term 'engineering leadership'. However, in many cases that is where the commonality ends. There is a need to bring conceptual analysis to engineering leadership programs across universities to see how they are similar and different. This paper meets this need by presenting a set of important organizational dimensions that provide a novel framework for understanding patterns in how engineering leadership programs are structured and delivered. First we review the literature and describe the programs studied, and then we show how universities differ along the key organizational dimensions. Later we show some interesting patterns or clusters of similar programs before concluding with the implications for engineering education.

Literature review

The majority of literature on engineering leadership, especially within a university context, consists of program descriptions in which engineering educators share their pedagogical innovations. There are a few researchers who have conducted program evaluations of engineering leadership across institutional contexts [5-7] and these provide a useful starting point for this study. Both Froyd and Graham sought to evaluate program effectiveness with the end goal of large-scale educational improvement. However, they each interpret the diversity of program structure and pedagogy differently – on the one hand as demonstrating attempts at reform that are not yet effective; and on the other hand as hope for building a larger coalition of contextually relevant initiatives. Our paper adds to the ongoing conversation about developments in engineering education by analyzing core differences and similarities across engineering leadership programs in a holistic way.

Recent work in the field has more clearly defined engineering leadership as professionally relevant forms of influence[8] and has also begun to compare the stated objectives and learning outcomes of engineering leadership programs[9].

Engineering leadership programs described in the literature range substantially in their focus, delivery channel, and pedagogy. Three recurring foci are entrepreneurship and innovation[10-11], personal and professional growth[12-14], and global citizenship[15-17]. Delivery channels include integration into core courses[18], smaller cohorts[11], curricular minors[19-20] and co-curricular programs[21-23]. Pedagogical strategies range even more widely from direct instruction[24-26] to problem-based learning[27] to case studies[28-30].

The extent to which these strategies support the development of successful or socially responsible engineering leaders has not yet been determined in any systematic way. We argue that before any large scale, cross-program evaluation can even be conceived of, we must first build conceptual clarity around program focus, delivery channel and pedagogy, extending to other aspects of organizational design.

Methodology

To understand what factors characterize and shape the types of leadership initiatives that take root, this study builds upon the literature reviewed above to explore how North American engineering schools integrate leadership into their offerings. We focused on the universities that had well recognized and explicitly defined engineering leadership initiatives. We were interested in generating coherence within that group, and grounding programs in the organizational context of a university. The goal was not to fully capture and categorize every single activity, nor to evaluate the effectiveness of the existing programs. Rather, this study sought to expand our understanding of how schools of engineering are conceptualizing, defining and implementing initiatives to offer more 'leadership' to their engineering students, based on their own definition of the term.

Initially, we created a list of 35 engineering leadership programs in Canada and the United States, by searching the web for 'engineering leadership education' and using our knowledge of the active members of key engineering education conferences and communities. The list was not intended to be representative, but rather to include the well-known programs as well as some variation in approach to leadership education.

We identified fourteen key informants through personal networks and participation in the network known as COMPLETE (The Community of Practice for Leadership Education for the Twenty-first-century Engineer). We conducted semi-structured telephone interviews with senior program leaders. For each program, we started with web-based research as preparation for interviews that ranged in length from thirty minutes to two hours. Each interviewee was sent four broad question areas in advance: overall approach to engineering leadership, connection between technical engineering and leadership, resources and networks, and evaluation/assessment. Most interviewees shared resources (presentations, course syllabi, strategic planning documents) to supplement their verbal descriptions of how their programs operate. Interviews were recorded and transcribed. Case records were developed to summarize the key aspects of the fourteen programs studied in a common structure, and these case records were reviewed by interviewees to ensure accuracy. The universities included are briefly described in Table 1 below, and are ordered by the date their engineering leadership work started, from oldest to newest.

Table 1: Program Descriptions

University (year program began)	**Brief Description**
Tufts University (1987)	Tufts Gordon Institute is one of the oldest engineering leadership programs. Its most substantial offering is the Masters of Science in Engineering Management, an intensive and highly integrated degree built around two intensive industry-based projects. The program integrates leadership in teams and organizations with technical learning about product development and business.
Northwestern University (1990)	Northwestern's Center for Leadership is a university-wide unit that is housed in the College of Engineering. The program focuses on partnering with other departments and colleges to embed leadership into their existing programs, while also running a few stand-alone courses on leadership.
Penn State University (1995)	Penn State's Leadership Development Minor was established in 1995 and has been stable in terms of content and participation for almost 20 years. A series of linked courses and an international service-learning project make up the minor.
University of Toronto (2002)	University of Toronto's Institute for Leadership Education in Engineering (ILead) began as a small co-curricular program in Chemical Engineering, and over time has grown into a faculty wide institute. Currently offers fourteen elective courses and numerous co-curricular programs on engineering leadership for undergraduate and post-graduate students. U of T also has a dedicated team doing research on engineering leadership.
Massachusetts Institute of Technology (2007)	Massachusetts Institute of Technology (MIT)'s Gordon Engineering Leadership program is a well-established co-curricular program targeting undergraduate students. Students work experientially to develop hands on leadership skills, building towards a competency model, and a small subset complete a second year as senior fellows, running leadership labs and mentoring younger students to "learn by doing."

Northeastern University (2008)	Northeastern's Gordon Engineering Leadership program offers a customized masters degree or a stand-alone graduate certificate for master's students. The program offers courses on leadership and product development in an engineering context, with an industry-based project, and integrated leadership labs. Incoming students have an average of five years of industry experience.
Iowa State University (2009)	Iowa State University offers university-wide Certificates and Minors in Leadership. These include a series of linked 1-credit courses, a project and leadership electives. Engineering students have access to both, and take the same core courses but have engineering specific leadership course electives. Leadership is also explicitly integrated into the graduate attributes of the Construction Engineering program.
Southern Methodist University (2010)	SMU's Hart Center for Engineering Leadership has a dual mandate for career development and college-wide leadership development. SMU embeds its learning in first and final year design courses, and offers assessments to every single incoming freshman.
Rice University (2010)	The Rice Center for Engineering Leadership (RCEL) offers a certificate in engineering leadership that is a combination of coursework, experiential labs, an internship and a final presentation. RCEL experimenting with a course on leadership coaching in partnership with the business school and in the process of developing a professional master's degree in engineering leadership.
Brigham Young University (2011)	BYU's Weidman Center for Global Leadership focuses on developing leadership and global agility in engineering students. The Center supports core faculty in teaching a core course on engineering leadership for all second year engineering students and supports a few small co-curricular initiatives.
McMaster University (2011)	McMaster's SELECT is a small co-curricular program offering tangible skill development related to leadership for students who self-select into the program. The program has recently gone through a strategy shift towards more career-oriented topics in its offerings.
Cornell University (2012)	Cornell's Engineering Leadership Program offers a certificate in engineering leadership that is built around an in-depth passion project and engineering leadership courses. Cornell also provides a series of teamwork-based interventions in the core curriculum.
University of Texas at El-Paso (2013)	University of Texas El Paso offers a Bachelor's degree in Engineering Leadership (known as E-LEAD), which integrates leadership throughout the entire undergraduate experience for a cohort of students. E-LEAD students take a spine of courses as a group and integrate with other engineering students for their other courses.
Western University (2014)	Western University's Engineering Leadership and Innovation Certificate is a partnership between the engineering faculty and the

	Ivey school of business. Courses focus on venture creation, entrepreneurship and core leadership skills in an engineering corporate context.

Distribution across key dimensions

One of our goals was to develop a conceptual framework to make sense of large differences in engineering leadership programs, starting with fundamental questions of purpose and end goal, through to the specifics of program implementation. To do this, we employed a modified version of analytic induction[31], whereby we started with some of the organizational dimensions uncovered from our literature review, and throughout our cross-case analysis added key dimensions that helped in distinguishing differences among the programs studied. We proceeded in an iterative fashion, and eventually seven dimensions emerged, which we were able to apply to all 14 universities studied. We later tested these seven dimensions with key engineering leadership program leaders (many of whom had been informants in the research) at the November 2015 meeting of the COMPLETE network. The framework is intended to clarify and distinguish programmatic differences using a set of dimensions that hold conceptual meaning across all cases. This is a descriptive and analytical framework, not an evaluative one, and so dimensions have been carefully constructed to ensure that both ends of the continuum are framed neutrally. Table 2 summarizes each continuum and the two ends of the spectrum proposed.

Table 2: Summary of key organizational dimensions

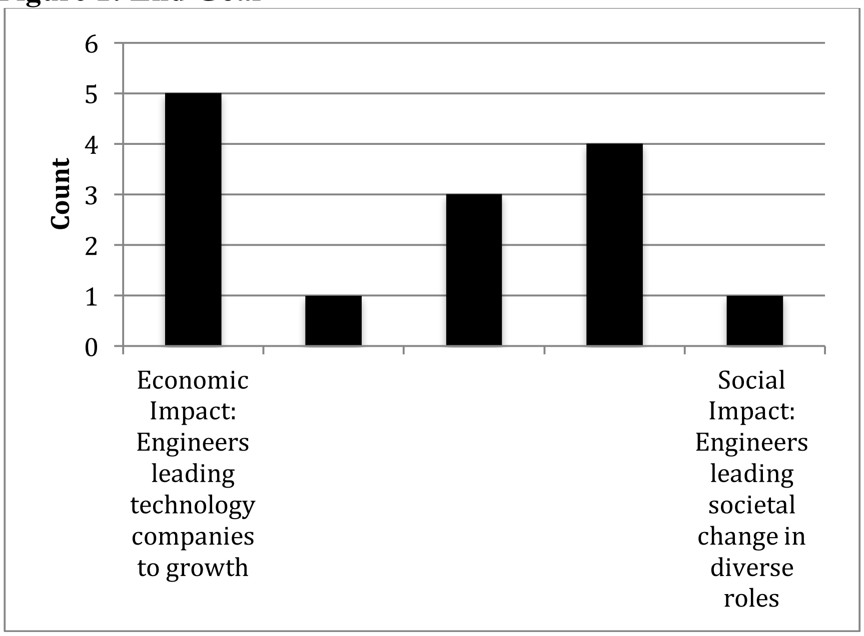
Dimension	**Range of the spectrum**
1) End goal	Economic impact to social impact
2) Application of leadership learning	Theory to practice
3) Scale of leadership action	Individual to organizational
4) Leadership emphasis	Process to position
5) Participant selection	Inclusive to exclusive
6) Compulsoriness	Core/mandatory to optional/self-selection
7) Integration	Integrated to separate

Each spectrum is described in more depth below, and examples are given to illustrate the extreme ends of the spectrum. University names for each of the data points have not been used to maintain privacy and anonymity. We checked with study participants to ensure the accuracy of our interpretations of where they fall on each dimension. Most informants were able to provide constructive feedback on their ‘ratings’ in advance of the manuscript being published.

1) End goal – economic impact or social impact?

What is the ultimate purpose or end goal of the leadership program? For each case this was inferred from stated aspirations such as vision or purpose statements, and triangulated by looking at evaluation frameworks to see what metrics or indicators programs are using to track long-term success.

Figure 1: End Goal



On one end of spectrum, several programs focus on helping engineering graduates step into leadership roles within technological companies to lead those companies to growth, market success and ultimately an economic impact. An example of this is Northeastern's Gordon Engineering Leadership program:

"There is a fundamental disconnect between industry needs and the output of engineering education. Conventional engineering education is necessary but not sufficient, and the reason we exist is to fill the gap to fulfill industry needs."

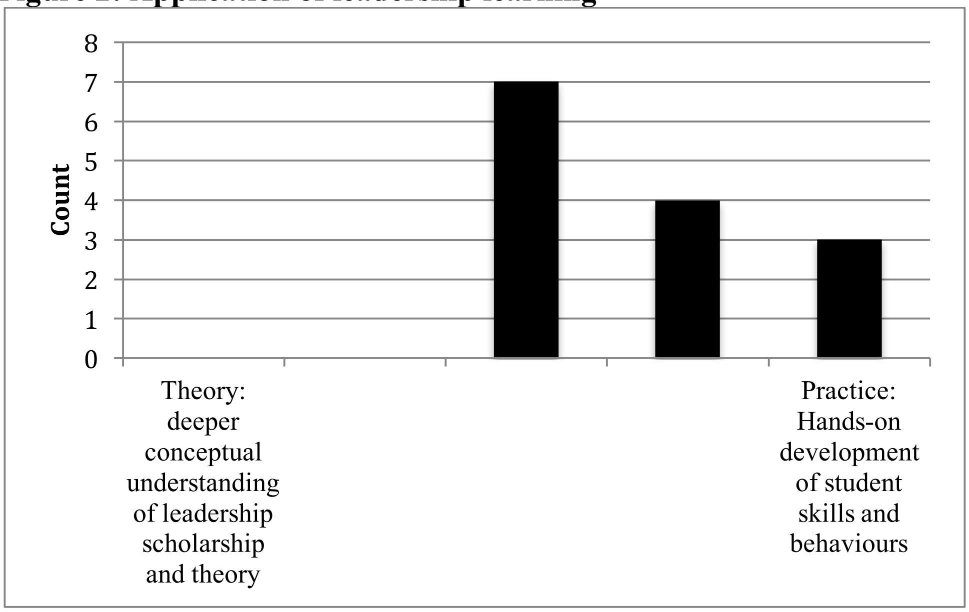
On the other end of the spectrum, a growing number of programs are focused on developing socially aware engineering graduates who seek out and make meaningful contributions to societal challenges through any type of organization or role. This is a more complex vision of success, and is harder to build an evaluation plan around, as there are more possible outcomes and definitions of success. An example of this extreme comes from Cornell's Engineering Leadership Certification Program:

"Engineers need to step up to face society's toughest challenges. We need to grow powerful leaders who can take on world's biggest challenges with knowledge, skills and courage."

2) Application of leadership learning – theory or practice?

This spectrum looks more closely at the intended learning outcomes, or content. What are program participants actually learning about, and where do we expect them to apply that knowledge?

Figure 2: Application of leadership learning



On one hand, leadership learning is applied to advance theory or scholarship. This would look like courses and research programs that study models, theories and approaches from an academic standpoint in order to understand and evolve the theory of engineering leadership. An individual example of this would be the University of Toronto's active support and supervision for a PhD student studying teamwork in engineering teams as part of a dissertation.

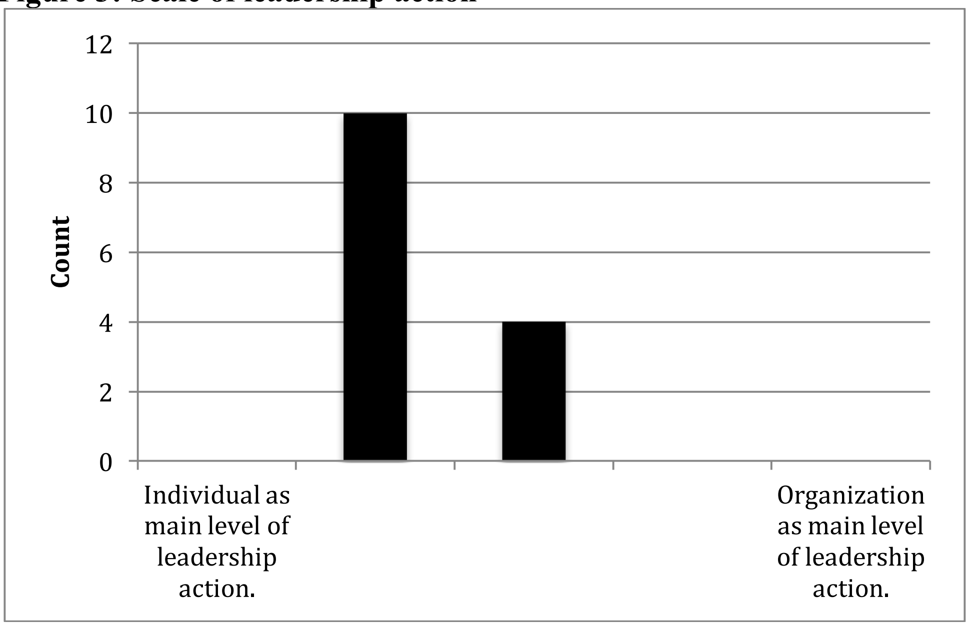
The other end of the spectrum is practice, or leadership development. This refers to the actual skill development and behavioural change involved in improving students' competencies as leaders. A number of programs exhibit this extreme, and one example is Tufts' Masters of Science in Engineering Management, which focuses on integration of skills and real world application in corporate engineering contexts.

The majority of programs are strongly oriented towards the application of leadership learning to practice. Very few programs are aiming to produce new research or scholars in engineering leadership, and most seek to improve the capacity of their graduates to lead in the world, regardless of the end goal of those behaviours.

3) Scale of leadership action – individual or organization?

This continuum looks at the implicit assumptions and mental models of what leadership means to program architects. This is one of the most difficult dimensions to objectively or externally understand, as it is typically not explicitly stated or described. Some program leaders were asked directly what leadership means to them or their program, and in other cases the mental model was deduced through a combination of program philosophy articulations and the content of specific program elements (e.g. syllabi, workshop content, assessment frameworks).

Figure 3: Scale of leadership action



On one end of the spectrum, leadership is understood as an individual phenomenon, and individual people (leaders) have agency over their surroundings so as to achieve their goals. This was by far the most common mental model of leadership in the programs studied. An example of this is McMaster's SELECT program, which *"focus[es] on what engineering leaders do. What they need to make decisions."*

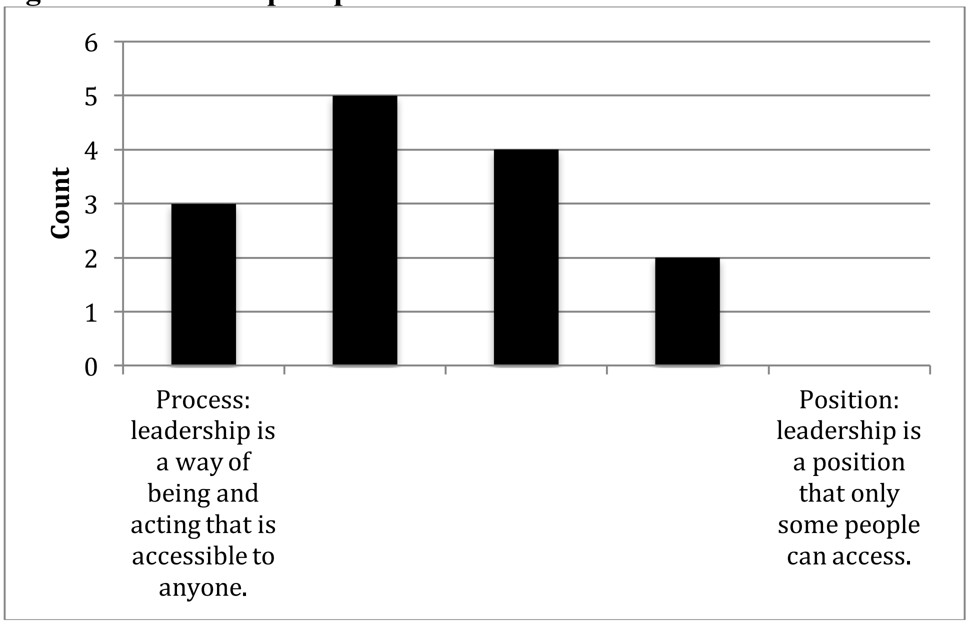
The other end of the spectrum is a mental model of leadership as an organizational phenomenon, understood as the way that engineering organizations lead within an industry, or influence other organizations. An example of a specific course that illustrates this end of the spectrum is MIT's 'People and Organizations' course for second year students in the Gordon Engineering Leadership program.

Much like the MIT example, some programs allocated a small portion of their curriculum to teaching students about leadership as an organizational phenomenon, while most of the emphasis was on students understanding themselves as leaders.

4) Leadership emphasis – process or position?

This spectrum contrasts the definition (or emphasis) of leadership by looking at whether leadership is conceived as a shared process, or a position that only some people can access.

Figure 4: Leadership emphasis



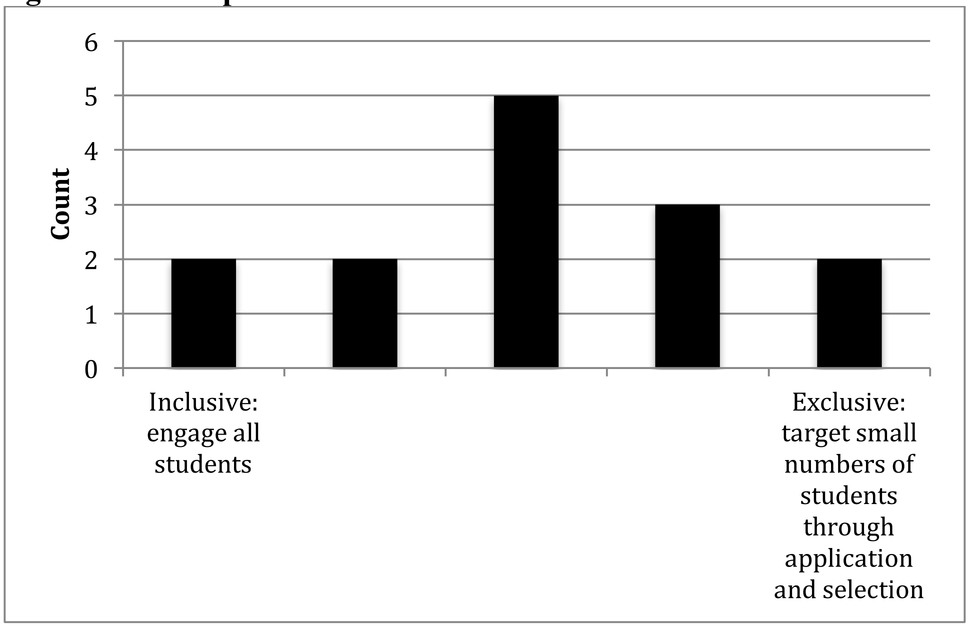
On the one hand, some programs tend to promote the view that anyone can be a leader because leadership is more of a process than a position, and that you can exert leadership even with no formal authority. An example of this perspective is the textbook for two University of Toronto engineering leadership courses, which is titled "Everyone a Leader: A Guide to Leading High-Performance Organizations for Engineers and Scientists."[32]

The other viewpoint is that in every situation there is a clear leader, whether by formal appointment or informal emergence. An example of this from Northwestern University is the Field Study in Leadership course. Students apply to get into the course, and must show that they spend at least 16 hours a week in a position of leadership to be admitted. The rationale behind this course requirement is to ensure a minimum level of existing commitment, which then enables participants to have enough depth of experience to get the most learning and growth from the experience.

5) Participant Selection – inclusive or exclusive?

This dimension refers to the intended strategy of the program team: is it a program meant to reach all students, or only a few? Sources of information on participant selection span from explicit articulations, in the form of strategic goals, triangulated with actual reach of programs in terms of the number of students engaged as a fraction of the total engineering population at the institution.

Figure 5: Participant selection



One extreme is full inclusivity: leadership is for all engineering students, regardless of their interest in the topic or their natural aptitude for it. Southern Methodist University's explicit strategic goal that "*leadership is for everyone*" is a strong example of this strategic intent.

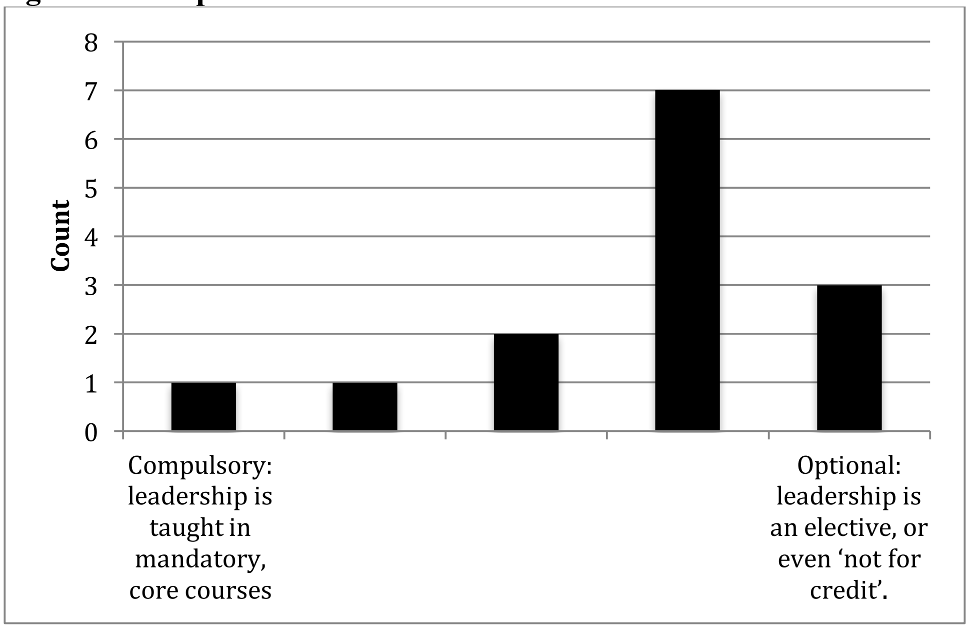
The other extreme is high exclusivity: leadership is for the select few who have the willingness and ability to develop themselves. An example of exclusivity is the University of Texas at El Paso's Bachelor of Engineering Leadership degree. The leadership courses are not open to students taking traditional engineering degrees at UTEP. It is important to acknowledge that first year students apply to the E-LEAD degree straight from high school, so that are not being selected from within the engineering student body based on their demonstration of leadership. Yet, students in other majors are allowed to switch majors into Engineering Leadership, but must reside within the program for a minimum of three years.

The distribution of programs is well spread across this spectrum, with a leaning towards the exclusive end of the spectrum.

6) Compulsoriness – compulsory or optional?

Compulsoriness refers to where engineering leadership programs fit within the 'hierarchy' of the engineering curriculum, whereby core, mandatory classes are the top of the hierarchy, followed by electives (technical or humanities), and finally co-curricular which are not for any academic credit whatsoever.

Figure 6: Compulsoriness



On the one end of the spectrum is engineering leadership courses that are compulsory, and delivered to all engineering students in a given university. An example of this is Brigham Young University's engineering leadership course, which is mandatory for all second year students, with the recent exception of electrical and computer engineering students, for whom it is optional. The course is taught by tenured engineering faculty members, which is another notable outlier from most of the programs studied, where professors of the practice typically teach engineering leadership courses.

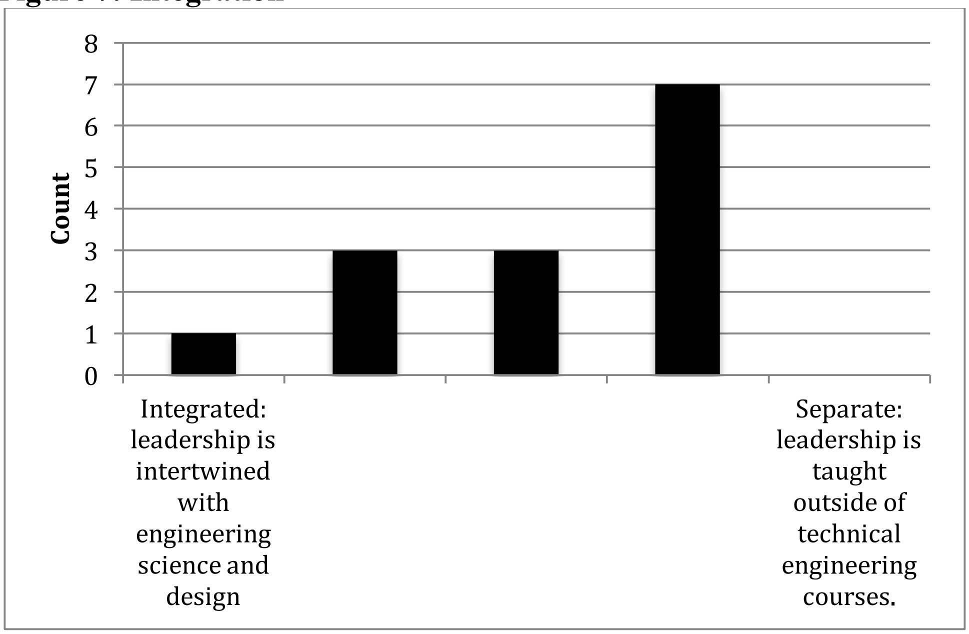
On the other end of the spectrum are programs where leadership is optional to engineering – it is an elective course or co-curricular (not for credit). The implication here is that leadership is nice to have, but not necessary for an engineering graduate. An example of this end of the spectrum is Western University's newly designed Engineering Leadership and Innovation Certificate, which is a suite of elective courses that students need to opt into. The program is very new and only a few dozen students are enrolled in the certificate, out of a student body of more than 2,000 undergraduate engineering students. However, the program is not intended to serve a large fraction of the student population.

Since all universities offer a range of different leadership courses and program elements, this spectrum is meant to be an average of the different activities. It should be acknowledged that the ability to offer core courses is often outside the sphere of influence of program designers. They may be constrained by their institution's priorities and their limited control over the formal curriculum.

7) Integration with technical engineering courses – integrated or separate?

This last continuum looks at the degree to which leadership is seen as integral to core technical engineering competencies or a completely separate set of skills and knowledge. In particular we look at how leadership is taught.

Figure 7: Integration



On the one hand, leadership can be highly integrated into existing engineering courses and defined as part of what engineers do. An example of this extreme is the modular design of Tufts' MSEM program, where parallel courses are taught by a team of faculty working to integrate and reinforce lessons from business, engineering and leadership. In this context, leadership is layered onto a set of product development and business strategy projects, especially in year one of the program.

On the other hand, leadership can be taught in separate courses by separate professors and applied explicitly to technical problem solving scenarios. Many of the stand alone engineering leadership courses offered by various universities exemplify this extreme, including the elective leadership classes offered by the University of Toronto where leadership concepts and content are taught independently of engineering content. While these are often very experiential courses, they generally do not embed leadership in a technical engineering context.

There are some contradictions in defining this spectrum. Almost by definition, this study has sought out to find and look at explicit leadership education programs, and so would systematically omit universities where leadership is fully integrated into the fibre of education and not explicitly mentioned, such as in military colleges. Olin College's holistic approach to engineering education could also fit into that category.

Clusters of programs

The seven dimensions provide an interesting way to look at how engineering leadership programs are distributed across a specific spectrum. They show in clear terms the substantial variations across universities in approaches to understanding the problem, and developing solutions that are embedded (or not) in the structure of the engineering curriculum. It seems reasonable to assume that programs may be able to better learn from and share with others who have similar goals and strategies to themselves, and so we were interested in using the dimensions to start to identify the programs that were the most similar to each other.

We wanted to see whether programs would 'cluster' together across multiple dimensions. If programs tend to conceptualize leadership as a position, does this make them more likely to develop cohort-based programs for a select few students? Or does it make them more likely to teach leadership as separate from engineering?

Given the subjective nature of the ratings, we didn't think that a quantitative analysis was necessary or appropriate. Instead just sequentially sorted all programs by their rating on a given dimension, and flagged groups of programs that tended to have a similar 'profile' across different dimensions. The results of that clustering are explored below.

Cluster 1 - Degrees integrating leadership with technical engineering

Three of the universities studied offer full degrees in engineering leadership and are distinguished by their tight integration of leadership into core (technical) engineering courses. All three offer small, cohort-based programs where program leaders have more control over design of the curriculum. Another dimension on which these three programs align is their focus on individual leaders, with two of the three having a clear end goal of economic impact in engineering companies. This clarity of end goal offers an opportunity for more focused assessment both in-program and after completion. A key difference among the three is that two are graduate degrees (Masters of Science in Engineering Management/Leadership) whereas the other is an undergraduate degree (Bachelor of Science in Engineering Leadership).

Another interesting difference is that two of the degrees only offer a fraction of courses exclusively to the leadership cohort. For the balance of their courses, the engineering leadership students are mixed in with students who have not opted for a full degree in the subject. It would be fascinating to study the interactions between students in these two cohorts in general courses, to see the extent to which the 'leadership' identities differ.

Cluster 2 – Developing social impact

Four of the universities placed a clear priority on the social impacts of engineering leadership. This cluster is more diverse than the first, but tends to focus on leadership as a stand-alone subject, rather than tightly integrated with technical engineering concepts. Perhaps linked to this, is the tendency for these programs to be elective or co-curricular, rather than integrated into core courses. This may be because their desire to define engineering more broadly, including explicitly working on social challenges, is at odds with the institutionally recognized definitions of engineering that center on the application of math and science. Interestingly, these social impact-focused programs were the most likely to emphasize organizational forms of leadership (although not to an extreme), possibly reflecting a broader systems view of engineering's potential contribution to society.

Cluster 3 – Influencing core curriculum

The third and final cluster that was observable included the two programs explicitly focused on engaging all engineering students in leadership education. This involves faculty buy-in and relationships with key administrators that are fundamentally different to developing small, targeted programs using self-selection mechanisms to recruit participants. Given the focus on undergraduate students, both of these programs are using a wider range of strategies: teaching mandatory courses on leadership to all engineering students; supporting the drafting of department-level learning outcomes to include leadership explicitly; and offering internal support to core team-based design courses. This third strategy is also being pursued by a number of universities whose main programs tended to be optional, and represents a good area for shared learning and defining good practice.

Conclusions

This study explored how leading North American schools of engineering approach engineering leadership education. We showed how these programs differ at various levels of organizational strategy, from goals to means to content, using a set of seven dimensions that emerged from the data through analytic induction. In general, engineering leadership programs have tended to deliver programs to small-scale cohorts of students, focusing on individual leadership skill development separate from the technical engineering curriculum.

However, by looking at the dimensions in combination, we were able to segment the growing numbers of engineering leadership programs into three distinct clusters: technical integration, developing social impact, and influencing core curriculum. These relate to the patterns in program focus that were identified in our literature review, but we have extended cluster definition to include a more robust organizational view of the similarities and differences. We expect that leadership educators would be able to exchange learning with each other more efficiently and productively within a cluster (compared to across clusters) because of shared assumptions and end goals. This presents a new strategy for planning committees of existing communities of practice to consider when designing workshops that bring together program leaders.

Based on preliminary testing of the findings with a group of more than twenty senior stakeholders representing fifteen universities invested in engineering leadership, we think that this broad framework can be evolved into a useful self-reflection tool for program leaders. It also can help early stage initiatives to think more critically about the implications of different design decisions for their leadership program architecture. We plan to test some of these applications in future gatherings of engineering leadership programs.

The overwhelming tendency for engineering leadership programs to develop and grow outside the formal curriculum, at least initially, poses an important set of questions for the respective accreditation bodies (ABET in the United States, CEAB in Canada) about why and how current incentive systems are forcing leadership education outside the core of engineering. At the same time, the emergence of the third cluster of programs, which focus exclusively on influencing the core curriculum to expose all engineering students to leadership, provides some early models for a different approach. Taking this approach involves a higher degree of partnership with tenured faculty members, embedding teamwork concepts in design courses, writing leadership into departmental learning outcomes, and potentially developing mandatory leadership courses. Some of these approaches may be challenging for programs that are staffed by experienced industry leaders (professors of the practice) or leadership experts. Those people may have an uphill battle in building credibility and trust with tenured engineering professors. In this regard, engineering leadership innovators and researchers need to continue to be aware of advances in engineering design education, and seek to collaborate more actively with practitioners in that field.

As an exploratory study, the framework we have developed appears to have some wider applicability to other engineering leadership programs. On the other hand, the findings in terms of how programs are distributed across key spectrums are not likely to be representative of all engineering schools in North America. We intentionally sought out universities that self-identify as being at the leading edge of this nascent field, to understand the fundamental differences in approach being taken.

One area for future study is a deeper analysis of different organizational trajectories from initial inception to stable operation (and potential collapse or reorganization) as the programs studied varied widely in their length of existence and might be better understood through the lens of where they are at in an organizational growth and change cycle. This information (how programs get started and grow) would be highly valuable to the next wave of programs.

Another place where there is a clearly articulated demand for better research is the development of a clear typology of specific program elements at a more tactical level. This study alone uncovered nearly 200 different examples of program elements (whether a co-curricular set of workshops, a service for club leaders, an individual course on engineering leadership, or an intervention in a core course) that can be better categorized and defined to create a more clear menu of offerings for program designers and architects. Beyond simply defining these ‘building blocks’, there would clearly be a major benefit to investing in systematic program evaluation of the effectiveness of different programs/activities in achieving specific learning outcomes. Program evaluation is systemically under-developed across all of the universities interviewed in this study;

cross-institutional collaboration to develop evaluation practices or metrics would be an important first step in developing a legitimate set of 'best practices' for engineering leadership.

By looking beyond the individual characteristics of one specific program to understand commonalities and differences in the organizational aspects of how leadership programs exist within engineering schools, this study aims to develop a stronger sense of coherence within the field.

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