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Engineering Leadership: Bridging the Culture Gap in Engineering Education

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Abstract
The world needs engineering graduates that can develop solutions that extend beyond the purely technical aspects of solving a challenge or problem. Engineering leadership education provides a strong mechanism for engineering educators to develop an engineering mindset that embraces the development of a depth and breadth of non-technical skills as being a key element of engineering education. This can lead to engineering graduates that are comfortable working across disciplines and contribute broadly to creating positive solutions to large and complex sociotechnical challenges. Notwithstanding, developing and integrating non-technical skills associated with leadership, such as social intelligence, developing vision and working in interdisciplinary teams beyond engineering is a systemic challenge. In this paper, the authors propose that a major barrier to systemic change toward enhanced non-technical skill development is the existing culture in the engineering education institutional environment. This paper is based on our personal experience in both advocating and implementing a broader mindset in the engineering curriculum. We begin by exploring the tensions in the culture of engineering education through the lens of Hofstede's cultural dimensions. We then follow with a discussion of the co-contraries that exist in engineering education within the bounds of these cultural dimensions. We conclude with thoughts on how concepts of engineering leadership could be leveraged to influence culture change that can positively influence the curricular aspects of engineering programs, as well as within the institutional environment. The work in this paper provides a baseline for discussion on how engineering educators can work to bridge the culture gap that arises from the systemic cultural tensions.

1. INTRODUCTION

1.1 Motivation

This work is motivated by our own efforts in trying to effect change as it relates to incorporating interdisciplinary approaches and concepts within the curriculum, both internally at our own institutions, and broadly as members of national engineering education communities of practice such as the Canadian Engineering Education Association (CEEA), the CEEA Sustainable Engineering Leadership and Management (SELM) special interest group, the National Initiative on Capacity Building and Knowledge Creation for Engineering Leadership (NICKEL), the American Society for Engineering Education (ASEE) and the ASEE Engineering Leadership Development Division (LEAD). We are instructors with both industry and academic experience who have spent many years teaching interdisciplinary design at our own institutions. We believe that beyond its technical roots, engineering is a leadership profession. To address the complex sociotechnical challenges of today, engineering students need to develop comfort with, and proficiency in, the foundational skills and mindset of leadership. We have interacted with faculty and senior administrators at many institutions nationally and globally, with industry partners, and as engineering educators who are passing on beliefs, values, and engineering culture to our students and to faculty and graduate students we engage with in workshops and mentor. It is also motivated by our observations of our broad community of practice as we have watched members of this community effect change and struggle to effect change both in courses and in the systems that support the delivery of engineering education. We have witnessed change happen only to be reversed or sunset as the engineering vision and engineering culture pendulum swings back and forth depending on who is currently shaping the institutional vision and sometimes even the departmental vision. Interestingly, this pendulum is not always in sync with what is observed in industry. In industry, the vision changes with the economy, societal constraints, tolerance, and events outside our sphere of control. We are members of, and contributors to, an engineering education faculty culture that demands high performance in all aspects yet rewards, privileges, and values certain aspects over others. We live and work in a culture that tips strongly towards work on the work life balance scale and embraces burnout behaviour.

1.2 Co-contraries and change in engineering education.

Change in engineering programs is a balance between those who are driving change and those who resist change. These tensions can often be seen in the form of co-contraries [1] which are founded in the concept of polarities [2]. Co-contraries may be in apparent opposition but are actually interdependent pairs that exist on opposite ends of a spectrum. For example, work-life balance could be thought of as a co-contrary. It is not work <u>against</u> life but rather a mix that needs to be <u>managed</u> as the dynamic between work and life demands ebb and flow. To reflect this, co-contraries are often represented as work && life, instead of work vs. life.

Co-contraries result in tensions in engineering culture based on beliefs and values that have been developed and passed on from one generation of engineering educators to the next. The engineering educators pass the culture to the undergraduate students, who in turn become either the engineering professors or the professional engineering mentors themselves. The base cultural values and beliefs, and the balance between the co-contraries associated with the engineering discipline instilled during the undergraduate years can remain largely intact over the course of a working lifetime. Notwithstanding, culture and the balance between co-contraries, can often diverge or evolve based on work and life experience. Experience can disrupt and challenge culture and beliefs that no longer are consistent with changing worldviews, goals and objectives both personally and professionally. Tension arises when changing needs and circumstances are no longer consistent with the dominant culture and the managed balance between the co-contraries.

The implementation of the Canadian Engineering Accreditation Board (CEAB) and ABET Graduate Attributes (GA) as an accreditation evaluation tool is an example of an educational driver that changed the balance of the educational focus related to the co-contrary of input &&. outcome based educational quality assurance approaches in engineering education. This major shift to outcome-based quality assurance from input-based accreditation units, challenged many deeply held personal beliefs and values that are directly linked to traditional engineering education culture. A shift in focus to articulate broader learning outcomes in the curriculum to support non-technical skills required of professional practice was often met with significant resistance. Challenges raised to implementing the changes required included rebuttals that nothing could be removed in the already full curriculum, despite the longstanding feedback from graduates regarding numerous courses and activities that were never actually used in practice.

A second example of cultural resistance to change has been the slow adoption of student-centered pedagogies such as active learning. The outcomes-based approach requires a shift from a teacher centered pedagogical approach to a student-centered approach. Even so, this slow adoption of active learning is apparent despite a dramatic increase in our capabilities and capacity to leverage instructional technologies, and that as project-based design education has become common in engineering programs. Active learning pedagogies challenge the more traditional teacher-centered pedagogies such as lectures, which are the dominant form of delivery. This slow adoption is apparent notwithstanding the large body of evidence demonstrating the efficacy of student-centered approaches. This resistance to active learning can also be noted in both engineering educators and engineering students.

1.3 Systemic challenges to change in engineering education

In addition to personal beliefs and values linked to the traditional culture of engineering education, there are systemic and institutional challenges that support and drive resistance to change driven externally by societal or industry needs. These systemic challenges include financial incentives and constraints, tenure and promotion practices, the definition of teaching and research, the increasing pace of technological change in the instructional and research environment, and the drive for institutional prestige. There is systemic resistance to change related to evidence-based teaching practices with respect to the graduate attribute inclusion and assessment, student centered pedagogies and indeed the value of engineering leadership education.

These systemic challenges drive cultural beliefs, values and practices and cultural artifacts in the engineering education environment that are resistant to change. For example, these systemic conditions lead to the perspective that faculty must be experts, which leads to the belief that they should be on the center stage. The perspective that research and research professors are more valuable and prestigious than teaching and teaching professors, as it brings in additional funding in the form of research grants and allows researchers to fund and graduate highly qualified people (HQP), leads to the belief that teaching is less of a priority notwithstanding that it is funded by student learning grants and tuition. An example of a systemic institutional aspect that reinforces the high value place on research, is the common need for engineering education focused faculty to demonstrate performance in evaluations that includes peer-reviewed journal publications. This performance expectation, added to a high level of teaching activity, greatly impacts how engineering professors and instructors spend their time, and the ever-increasing workload often becomes excessive for many. As members of the community, we see the evidence of the impacts of this in the typical paper deadline extensions required at engineering education conferences. We see it via an understanding among collaborators across institutions that this has worsened post COVID. Another example of a systemic cultural aspect can be seen in the evaluation of undergraduate students, with a prevalence of high stakes academic assessments where students in (typically) larger classes must demonstrate their knowledge by passing high stakes midterm and final exams. This results in competitive grade rankings that can impact their career success out of proportion to the accuracy of the assessment that was used to create the grade. Lower stakes assessments strategies such as competency-based assessment, where students have multiple opportunities to develop and demonstrate competence akin to the way engineers develop expertise after graduation as an engineer in training and/or as a graduate student, is not as prevalent.

2. FRAMING CULTURE IN ENGINEERING EDUCATION

2.1 Defining a Cultural Framework

To this point, we have been discussing engineering educational culture without defining it. Based on our experience with the challenge of defining engineering leadership, for which a common definition remains elusive [3], we believe it would be useful to try to "frame" rather than define the culture of engineering education. To analyze the culture of engineering education, Godfrey [4] proposed a theoretical model for analysis based on Shein's [5] model of organizational culture. The model is built on the basis of Artifacts, Values and Assumptions that can exist within a culture at any specific institution.

To move beyond analysis of institutional culture to a general categorization we are looking to represent the elements of culture along a continuum of competing (or opposite) priorities and to identify an approach to analyze and effect change by addressing the nature of the balance that needs to be managed between the priorities. To set a frame to examine the general culture of engineering education, we use Hofstede's Model of the Dimensions of Culture [6] and examine the general nature of the engineering culture by looking at the observed artifacts, values and assumptions inherent in engineering education.

2.2 Hofstede's Model and Engineering Education Culture

Hofstede's model of cultural dimensions has been commonly applied to describing the broad culture observed within nations, with the caveat that individuals within the nations can show variations from the broad cultural norms. Five cultural dimensions in the model are: power/distance, uncertainty avoidance, individualism/collectivism, masculinity/femininity, long-term/short-term orientation.

To explore cultural meaning in the context of engineering education we look to describe and look for examples of each of the five cultural dimensions, and to provide examples of co-contraries that are prominent related to each dimension. These examples of co-contraries have been derived primarily from our experience working as engineering educators in a university setting both in our own institutions and more broadly in our national context. The purpose is not to identify theses as the only, nor even the highest priority co-contraries, but it is to provide a frame as well as a starting point for educators to explore the cultural aspects that can lead to positive change.

1. **Power/Distance**: Examines how inequalities in prestige, wealth and power are observed. High power/distance would be observed through high deference to authority. In the context of engineering education culture, we can observe the manifestation of power/distance in the relationships between instructor and student, between instructors and their peers, and between instructors and this institution. These can be expressed in the following co-contraries:

Instructor/Student - ***"Sage on the stage" && "Guide on the side"***

Student/Instructor – ***"Valued mentor" && "Gatekeeper"***

Instructor/Instructor - ***Initiative lead && Initiative follower***

Instructor/Institution - ***Service && Teaching/Research***

Student/Institution – ***"Customer" && "Learner"***

2. **Uncertainty Avoidance**: The approach to, and comfort with, addressing uncertainty of what is not known. High uncertainty avoidance can be observed through cultural artifacts that reduce risk, such as strict laws or codes. In the context of engineering education culture, we can observe the manifestation of the uncertainty avoidance in the way that instructors and students approach solutions to engineering problems. This can be expressed in the following co-contrary:

"Right" answer of math and engineering science &&
Many answers of practice, design and interdisciplinary approaches

3. **Individualism/Collectivism***:* The degree to which people operate as individuals or in groups, and the extent to which the focus of activity is on individuals or on groups. In the context of engineering education culture, we can see the manifestation of individualism/collectivism in the way that work is evaluated and rewarded. This can be expressed in the following co-contraries:

Student and instructor perspectives – ***Individual work && Team work***

Student and instructor perspectives - ***Competition && Cooperation***

Instructor perspective – ***My courses && Collective program courses***

Instructor perspective - ***Expert && Contributor***

4. **Masculinity/Femininity**: How aligned a society is with masculinity/femininity in the context of gendered norms. This is not the same as the number of males or females in a group. Masculinity refers to a culture that tends to value intellectual, rational, achievement and assertiveness over emotional, feeling, caring and cooperation. In the context of engineering education culture, we can observe the manifestation of masculinity/femininity in the expectations of work and the values placed in the curricular content. This can be expressed in the following co-contraries:

Curricular content: ***Technical && Non-technical***

*Prestige - Instructor and institution****: Research && Teaching***

Curricular content: ***Problem (narrow design) && Challenge (global context)***

Learning Approach: ***"Shared hardship" && Reflective learning***

Communication approach: ***Extroversion && Introversion***

Solutions approach: ***Pragmatic && Idealistic***

5. **Long-term/Short-term Orientation**: The degree to which the focus is on reacting to short-term needs or addressing longer term needs. In the context of engineering education culture, we can observe the manifestation of long-term/ short-term orientation in the cycles of the program and semester delivery. This can be expressed in the following co-contraries:

Student perspective: Current ***grades && Life-long learning***

Student perspective: ***Semester to semester thinking && Career goals***

Instructor perspective: ***Individual course && Integrated courses over program***

Instructor perspective: ***Semester to semester thinking && Program development***

3. FRAMING CHANGE THROUGH ENGINEERING LEADERSHIP EDUCATION

3.1 Principles of Engineering Leadership Education

In response to the need to address complex sociotechnical challenges and the need for engineers to communicate and work in interdisciplinary environments, instruction related to leadership skill development and formally constituted engineering programming has been growing over the past 20 years [7]. Engineering Leadership education is enacted in many ways within the curriculum and is delivered in a diversity of formats [8]. Notwithstanding this diversity and the lack of agreement on a singular definition, the principles of engineering leadership education engineering leadership programs are founded on the assumption that “leadership is not defined by a title or position, rather as a process that takes place between leaders, followers and/or team members” [3, 9]. This conceptualization centres the responsibility for leadership more on the collective, than on the individuals. Underlying this broad definition are a wide variety of leadership education principles, such as concepts adapted from business leadership programs, concepts related to the dynamics of the application of technical mastery, and experiential activities related to personal and professional development in areas such as personal values, social intelligence, social responsibility, reflective practice.

Given the dynamic interactions that take place between students, faculty, staff, and given the connections that engineering programs have to industry and engineering practice, this contextualized process-based approach to engineering leadership can serve the engineering education community well. Leadership principles may be appreciated by most engineering educators, but they are generally not broadly fostered in engineering education, nor inculcated in our professional development as members of the engineering education community. As our own personal development and awareness is influenced by what and how we teach, those that teach engineering leadership skill development, formally labelled as engineering leadership education or taught in courses such as interdisciplinary engineering design, could be leveraged as a resource within the faculty to facilitate positive cultural change in engineering education.

3.2 Applying Engineering Leadership Principles to Culture Change

Through our contextualization of the culture of engineering education using the lens of Hofstede's model of cultural dimensions, we have identified many co-contraries that exist in the culture of engineering education. We are using the concept of co-contraries to shift the view of the cultural priorities from a mindset of "competing positions to defend", to a mindset of "needed opposites" that are ongoing, and that must be managed to provide a positive and successful environment for curricular change.

We argue that to effect this cultural change and embrace a co-contrary view, engineering educators can leverage Engineering Leadership principles within our institutions. Leadership development is about gaining the skills and learning the frameworks to manage and shift the balance point in the co-contraries with all those involved.

To demonstrate this concept, we have selected four co-contraries for discussion in the context of applying the Engineering Leadership education and examining cultural change. These four co-contraries were also selected based on our belief that shifting culture related to these co-contraries can be key opportunities for empowering the engineering education community to bring change to engineering education:

Instructor/Student - ***"Sage on the stage" && "Guide on the side"***

Curricular content: ***Technical && Non-technical***

Prestige - ***Instructor and institution: Research && Teaching***

Instructor perspective - ***Expert && Contributor***

"*Sage on the stage" && "Guide on the side*" - We have captured this co-contrary within the cultural dimension of Power/Distance. Except for project-based design courses, the typical undergraduate engineering teaching norm is a high power/distance culture based on teacher-centered lecture-based pedagogy. This contrasts with the culture in engineering practice, which tends to be a low power/distance with most professional engineers learning and contributing meaningfully across operations. Engineers, whether they are working at a university or in industry tend to be collaborative in their engineering work. Arguably, shifting the culture to reduce the power/distance between instructors and students would be beneficial from an engineering education.

Examples of engineering leadership concepts that are delivered to engineering students and could support a cultural shift in instructors that would reduce the power/distance relationship would be development of an awareness of social intelligence and developing coaching skills. This is not the only support or approach that would be needed (e.g., this shift can impact resource requirements), but an openness to a shift in the power/distance relations between instructors and students would help facilitate discussion on how to address issues that arise.

Technical && Non-technical - We have captured this co-contrary in the cultural dimension of Masculinity/Femininity. The cultural norm within engineering education is highly technical (associated with the norm of masculinity) and non-technical content is relegated to "complementary studies" courses or content that are required by accreditation or tend to be addressed solely in design-based courses. Feedback from students and industry indicates that much of the advanced detailed technical education is not utilized in engineering practice as technology changes rapidly and advanced math courses serve engineering science and research, more than they serve the greatest percentage of engineering graduates as they pursue their careers. Arguably, creating an openness in the engineering education culture to increase the meaningful non-technical component (i.e., associated with the norm of femininity) would broadly improve engineering education outcomes.

Examples of engineering leadership concepts that are delivered to engineering students and could support a cultural shift in instructors that would increase the femininity norm associated with non-technical content would be the exploration of personal values and organizational values related to vision, mission and values and how they relate to the overall curriculum. Notwithstanding that there are many challenges to increasing the non-technical content, shared value development can help shift the culture to allow for openness to meaningful change in this area.

Research && Teaching - We have captured this co-contrary in the cultural dimension of Masculinity/Femininity. The cultural norm within engineering education is that prestige (associated with the norm of masculinity) is highly attributed to the Research practice through many structural components of higher education, and specifically as they relate to Tenure and Promotion and compensation. Engineering education would benefit from additional focus associated with Teaching and the Scholarship of Teaching and Learning (associated with the norm of femininity). This is especially relevant as instructors are typically hired without any formal training in pedagogy and have limited support or incentive to improve courses year-to-year nor to integration of curriculum beyond their own specific teaching requirements. This challenge has been exacerbated by the accelerating pace of educational technology available to both instructors and students.

Examples of engineering leadership concepts that are delivered to engineering students and could support a cultural shift in instructors that would increase the femininity norm associated with non-technical content would be the exploration of personal values and organizational values related to vision, mission and values they relate to the overall curriculum. Notwithstanding that there are many challenges to increasing the non-technical content, such as where technical content might be reduced, shared value development can help shift the culture to allow for openness to meaningful change in this area.

Faculty as Experts - One additional cultural co-contrary that impacts all three co-contraries described above, is the co-contrary of **Expert && Contributor.** The faculty member as an expert is a deeply seated value of an engineering education and universities broadly. This is part of the systemic challenges that exist that makes it even more important for culture change within academic engineering departments that will help facilitate needed change. The culture of engineering education highly values, and arguably fosters the development of faculty as experts, and hires and arguably reinforces this value of expertise. The impact is that the cultural dimension of individualism/collectivism is highly individualistic in engineering education.

The highly individualistic cultural expectation for a faculty member to be an expert may result in the most challenging cultural co-contrary as it relates to limiting the ability for change in engineering education. Using the three co-contraries described above as examples, the extreme cultural need for faculty to be seen as experts supports the high teacher-centred pedagogy associated with "sage on the stage", drives the desire for highly technical education that builds on expertise and generates a small percentage of research-focused graduates, and also satisfies the high cultural prestige associated with research.

Examples of engineering leadership concepts that are delivered to engineering students and could support a cultural shift in instructors that would increase the collective norm associated with collectivism, are the concepts and values associated with followership. Shifting the culture to reduce the individualistic focus of being an expert would arguably result in more openness to change, for example in the creation of Tenure and Promotion requirements or in the breadth of material that faculty would be comfortable teaching.

4. MOVING FORWARD

In summary, we have argued that, although there are systemic challenges in engineering education, the major barrier to change in engineering education is the culture that exists within our academic engineering institutions. Shifting the culture can greatly improve the ability for change in engineering education without requiring disruptive systemic change. With culture change, systemic change can follow. Culture change will require the development of a broad capacity within engineering education for shared leadership, and a shift in mindset toward an openness to examine how to actively manage co-contraries such as those we have presented in this work. The development of capacity and a shift in mindset can be facilitated in a large way using principles that are currently taught in our own engineering leadership programs that have been growing over the past 20 years. Leadership is not a position, but a collective responsibility.

Looking through the lens of Hofstede's cultural dimensions, we have identified many co-contraries (opposing needs) that must be actively managed. It is important to remember that these are co-contraries, and that the approach to changing culture through examining the co-contraries allows for discussion and negotiation of interests, and positions culture change in a context that can be supported by applying engineering leadership development principles within engineering academic institutions.

In future work we intend to develop an approach to index engineering culture along Hofstede's or other relevant cultural dimensions associated with collective change in engineering education. We also intend to build out the descriptions, and examine in greater depth, the potential impact of culture shifts in key engineering education co-contraries, such as the ones we have put forward in this work.

Finally, we are hopeful we can begin a dialog on how we can leverage engineering leadership education to facilitate our capacity for meaningful change in engineering education.

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