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ASEE 2024 Paper—Examining Cultural Elements to Enable Change

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Examining Cultural Elements to Enable Change in Engineering Education

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1. Introduction

The future of engineering education requires engineering faculty, schools and programs to enact change in the curriculum to respond to the complex challenges in our world today and to recognize the socio-enviro-technical nature of engineering practice. Engineering leadership education is premised on the principle that developing strong leadership competencies is essential to effectively and appropriately enable the contextual application of the traditional technical competencies that are often the primary focus of undergraduate engineering programs. In our 2023 paper entitled *Engineering Leadership: Bridging the Culture Gap in Engineering Education* [1] we argued that a major barrier to change in engineering education, including the incorporation of engineering leadership into the curriculum, is the culture that exists in our institutions. We proposed that the elements and dynamics of this culture can be examined in the form of co-contraries (or opposites that need each other) and that the relative emphasis in these co-contraries reflects the engineering educational culture in a department, an institution or in engineering education as a whole. Example cultural co-contraries identified include: the power distance dynamic between the student and the professor; the nature of the distribution of effort between teaching and research; and the tension between technical and non-technical content emphasis and delivery.

In this paper we aim to look more deeply at cultural constructs associated with engineering education through a targeted literature review and integrative analysis of engineering education culture, the engineering culture of professional practice, the general theoretical constructs of culture and cultural dimensions in societal and organizational contexts with the explicit purpose of developing a foundational understanding of the cultural co-contraries observed and discussed in our 2023 paper. This foundational understanding can then be used to build a model for characterizing engineering education culture and evaluating positive cultural change and resistance to change in engineering education. We believe that capturing and understanding the cultural constructs associated with engineering practice and engineering education will not only be helpful in effecting change in engineering education, it will also support the need for engineering leadership [1], [2], [3] and followership education[4], [5] to be explicitly taught as core concepts at both the undergraduate and graduate level to support the requisite systemic changes in engineering practice and education to address the complex socio-enviro-technical challenges that engineering must address.

2. Motivation and Positionality

This work continues to be motivated by our own efforts to effect change as it relates to incorporating interdisciplinary approaches and engineering leadership concepts within the engineering curriculum, both internally at our own institutions, and more 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), Graduate Attribute Continuous Improvement Process (GACIP), Canadian Society for Chemical Engineering (CSChE), 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. We also understand that practicing and teaching engineering happens in the context and intersection of engineering culture, organizational culture, institutional culture and societal culture. In addition, we have experienced studying to become an engineer, becoming an engineer, practicing engineering, and becoming an engineering educator from the perspective of a woman and a man. We have taken atypical paths to becoming academics and have had the opportunity to consider engineering and engineering education culture using multiple lenses and perspectives including the technical details of engineering design and work, the systems and management of engineering projects and practice and the high-level systemic impact of engineering on our society and environment. We are both practitioners, teachers, and researchers. We are interested in identifying and understanding the larger scale interactions and influences that inform the development and progress of change and resistance to change in engineering education and professional practice culture.

3. Methodology

To develop a framework for characterizing engineering education culture and ultimately capture change that occurs along cultural dimensions pertinent to the engineering education context, we attempt to synthesize relevant literature related to culture and specifically engineering culture. The targeted literature review of institutionally embedded engineering culture from an education and practice perspective provides initial insight into exploring the question of how to frame engineering culture in the context of change. Ultimately the goal is to develop a useful framework to assess engineering education culture and examine culture change motivation that can help us explore culture in both the profession and in engineering education as a starting point for enabling systemic change in support of sustainable engineering and systems.

Our approach was as follows:

1. Review and summarize the engineering education literature for attempts to define and characterize engineering culture, with particular focus on cultural dimensions and impact of engineering culture on change.
2. Review and summarize literature on culture in the engineering profession, with particular focus on the intersection of the engineering profession with engineering education.
3. Review and identify cultural models that can provide guidance on capturing foundational cultural elements and characterizing these dimensions generally, including the concept of co-contraries.
4. Analyze the findings to create a framework for the drivers of cultural change that will allow the development of questions that form the basis of an engineering education cultural assessment tool.

4. Literature Review and Integrative Analysis

The literature review and analysis are blended into one section to allow us to synthesize our findings in parallel to the literature being reviewed. First, we examine description and analysis of engineering education culture and the impact of beliefs and assumptions on change and resistance to change. Next, we examine engineering practice culture in the context of institutional and societal embeddedness and the implications. We then review general cultural models related to the underlying assumptions, beliefs and values of engineering culture.

In this review and analysis, we attempt to explore the following themed research questions:

1. Engineering education culture
    - How is engineering education culture characterized in the literature?
    - How is engineering practice culture characterized?

- What are the similarities and differences between the education and practice cultures?

2. Change in engineering education culture
   - How is engineering education culture situated and what are the possible levers for change?
   - What are the roots of resistance to change?
3. Cultural frameworks to support assessment and analysis for change
   - How are cultures and dimensions of culture characterized in the literature?
   - How can we use these representations to characterize engineering culture and cultural change mechanisms in order to better understand engineering culture and leverage change?

4.1 Examining Engineering Education Culture

4.1.1 Observable Engineering Education Cultural Artifacts

Culture is generally defined as the shared beliefs, values and artifacts of a social group. In addition, cultural constructs shape the beliefs and values of individuals within a group [6]. Godfrey [7] [8] [9] noted engineering education culture as a distinct entity that is rarely defined in the literature. Nonetheless she cites work describing certain elements of engineering education culture such as the positivist research paradigm common in engineering and engineering education research; the premise that "propositional technical knowledge, discovered using a reductionist research paradigm, is the prime source of professional knowledge necessary for preparing students for the profession" [10]; teaching methods; the "overwhelming pace and load" designed to weed out "students deemed unfit"; and "mildly profane" student behaviour." She observes:

> "*The assumption that there are aspects of a common engineering education culture is reinforced by the abundant commonalities in behaviors and practices and thinking and understanding that resonate with engineering programs nationally and internationally.*" [9]

Historically, engineering and engineering education have been attached to national security and economic goals and entwined with corporate and business ventures. In the US the first engineering program was established in 1802 and funding for engineering programs was enshrined in the Morrill Act of 1862 indicative of the privileged position engineering education holds in US society [11]. Engineers work across industries and are at times the interface between management and the production and operation of the organization. The development of engineering as a profession and the focus of engineering education has been intertwined with current national and international needs hence preparing and educating engineers to meet the needs of the future is often a common theme in engineering program development, accreditation and reform [5][12], [13], [14]. Approaches to engineering education are variable across national borders and reflective of the national culture [13]. In the 1950's engineering education in the US evolved into programs heavy with math and sciences [13] and most engineering programs have retained this component globally as a result of accreditation meant to serve the need for engineering mobility across national boundaries. In 1989 the Washington accord was signed, and engineering education became more consistent across national borders and accreditation reinforced the heavy workload for accredited institutions. With the introduction of the graduate attributes there has been some recognition of the value of non-technical skills in engineering however this is at times met with a check box and tokenism mentality [12] [15]. Engineering education teaching and learning regimes can be research focused, industry focused or a blend [16] depending on the geopolitical location of the engineering school.

In reviewing engineering education culture in the literature, Godfrey [9] cites many studies and papers that describe and examine how engineering education culture contributes to resistance to change in engineering programs with respect to:

- the participation of women (Dryburgh, 1999; Hacker, 1983; Lewis et al., 1998; Tonso, 1996b)
- culture as gendered (Cronin and Roger, 1999; Lewis et al., 1998; Tonso, 1996b)
- culture as an agent in student attrition (Courter, Millar and Lyons, 1998)
- student engagement and enculturation (Ambrose, 1998; Lattuca, Terenzini &Volkwein, 2006)
- the development of engineering identity (Dryburgh, 1999; Stevens et al., 2008; Tonso, 2006)
- faculty cultures (McKenna, Hutchinson, and Trautvetter, 2008)
- campus cultures (Tonso, 2006)
- sub-disciplinary cultures (Gilbert, 2008; Godfrey, 2007; Murphy et al., 2007)
- national cultures (Downey and Lucena, 2005)
- assessment cultures (Borrego, 2008).

Godfrey [9] also cites studies of cultural change in engineering education, related to the role of

- institutional culture in effecting change (Covington and Froyd, 2004; Kelly and Murphy, 2007; Kezar and Eckel, 2002; Merton et al., 2004), and
- measuring cultural change (Fromm and McGourty, 2001; Lattuca, Terenzini, and Volkwein, 2006).

4.1.2 Observable Engineering Education Cultural Beliefs and Values

Beliefs such as meritocracy, ethics, complexity, difficulty, worthiness and stress are being studied with respect to engineering education culture and the impact on students and those who are excluded from the programs. To enhance our understanding of engineering education culture and change or resistance to change we explored the following areas:

- co-contraries and cultural dimensions [1]
- complexity and future needs [14]
- diversity equity and inclusion [12]
- meritocratic values [11], [17], [18], [19]
- challenging hegemonic values [20]
- engineering ethics [12], [15], [21]
- priority of research over teaching, inadequate time and resources [22]
- socio-enviro-technical leadership [1], [23]
- Stress culture [24]; [25]
- teaching and learning regimes [16]
- wellness [24]

Godfrey observed the study of engineering education culture may be impeded by a general lack of understanding of culture and cultural models among engineering educators and engineering education researchers and introduced Shein's model as the framework for her investigation. She noted engineering education culture and attitudes are observed by how engineering educators, departments and faculties relate to other university educators, departments, faculties, and governance. In other words, engineering education culture is embedded in the institutional culture of a university. It follows then that engineering education culture is somewhat shaped by the historical institutional structure and culture of universities, funding and regulatory ties with industry and government institutions *and the historical underlying assumptions, beliefs, and values of the institutions engineering is embedded in*. Cultural constructs are normative and describe the frequency of individual values and beliefs within a social group [26]. Cultural constructs influence individual behavior, motivation and belonging within a social group [27]. Conversely, individual values and beliefs influence the tendency for culture to be conserved or to change and can modify cultural constructs or retain them [26]. Values are guiding principles of individuals and social groups and motivate their behaviours. Schwartz [28] described seven characteristics of values:

- "Values are beliefs about the importance of desirable goals.
- When activated, values elicit emotion.
- Values are basic goals that apply across specific situations.
- Values consciously or unconsciously motivate behavior, perception, and attitudes.
- Value effects occur through a process of trade-offs among the relevant values.
- Values serve as standards for evaluating actions, people, and events.
- Values are ordered by importance in a relatively enduring hierarchical system."

Schwartz [29] proposed and validated [27] a circular motivational continuum of values that can be categorized in two pairs of motivational constructs: openness to change and conservation; self-focused and other focused. Individual and cultural values can be characterized in this manner.

Given the embeddedness of engineering education culture in institutional and societal culture, it is subject to pressure and influence of the larger social groups, the evolution of technology and engineering work and large-scale historical events such as the COVID pandemic. Remarkably, engineering education culture has remained somewhat stable in the face of this pressure [30] and the institutional priority of research over teaching continues to be a challenge [16], [22], nonetheless, program changes are occurring as sustainability issues are addressed at the course and program level. The workload remains a problem as there is a hesitancy to remove material from courses and programs even as new material is added, nonetheless, the examination of workload is occurring [31]. The number of female engineering students and engineers remains low for most programs and attrition remains high for female students in engineering [19]. Chemical and biological engineering programs tend to attract a higher proportion of female students. Female engineering students tend to reject feminism and affirmative action preferring the belief they are successful in engineering based on merit [19]. Interestingly, this belief held at Smith (all female) and Olin College (~40% female). Based on the literature, engineering education cultural beliefs include worthiness as an engineer is a result of completing a difficult program that requires hard work, sacrifice, and perseverance; merit is rewarded; success is based on individual technical competence. There is an assumption that hard work and challenging subject matter are necessary to become a good engineer and be able to design things that work and manage high stress environments. In addition, key values surfacing in the literature include: achievement, adaptability, commitment, competence (technical, problem solving, people), collaboration, flexibility, innovation, negotiation, persistence, perseverance, self-efficacy, and work ethic. Engineering education culture is constrained by the culture and regulations of the higher education institution, degree requirements, and the research and service requirements for faculty; accreditation requirements; graduate degree requirements; and the prevailing beliefs surrounding achievement, competition, difficulty, perseverance, collaboration, responsibility and meritocratic ideology.

4.2 Examining Culture in the Engineering Profession

4.2.1 Transitioning from Engineering Education Culture to Professional Engineering Culture

The engineering education culture Godfrey [7], [9] describes is somewhat different from engineering professional culture where there is a greater emphasis on non-technical skills, i.e. leadership, ethics, teamwork. While engineering education culture is characterized by studying engineering science, engineering design and math; engineering practice culture is defined by engineering work and obligations [2] where people and problem-solving skills are often emphasized over technical skills. According to Rohde et al. [11]and Seron et. al [19], engineering education culture prepares engineers to accept the realities of engineering professional culture with respect to the pervasive hegemonic and meritocratic ideologies accompanied by an intense commitment, workload and limited participation by women that are characteristic of the engineering profession. Women in engineering are often faced with difficult choices with respect to their legitimate desire to have and raise a family, a choice that has not typically impacted a man's career or ability to work fulltime [19]. Additionally, work-life balance can be a challenge with respect to workload in engineering studies and professional practice.

Engineering practice is regulated by self-governing professional bodies while engineering education is regulated by academic missions and institutional quality assurance frameworks and evaluated for "foundational academic qualification" by accreditation bodies. In Canada, accreditation is done on behalf of self-governing bodies and an accredited undergraduate engineering degree satisfies the academic requirement on the pathway to professional designation and registration with a self-governing professional association. The International Engineering Association (IEA) introduced graduate attributes into accreditation that include professional and technical skills engineers are expected to develop and have been added to the engineering education experience. The inclusion of more team and design work notwithstanding, most engineering programs are still heavily weighted towards individual achievement and performance consistent with some aspects of professional practice, especially that embedded in a corporate institution.

Ethics and equity are included among the engineering graduate attributes. Engineering students are expected to follow the expectations of academic integrity and the school/professional code of ethics. Professional engineers are bound by a code of ethics that is typically enforced by self-governing regulatory bodies. Professional engineers are bound by a duty to protect the public and the public interest. Hess et al. [12] identified multiple code of ethics artifacts that specify professional values, responsibilities, or connect ethics and diversity, equity and inclusion (DEI) in professional engineering. These artifacts represent the underlying belief that engineers have an obligation to society irrespective of the demands of their role and responsibility to their employer. The examination of multiple codes of ethics by Hess et al. [12] demonstrates many encapsulate professional values, recognize the impact of engineering on the quality of life of all people and offer specific guidance for incorporating Diversity, Equity and Inclusion (DEI) into professional practice and state the values honesty, impartiality, fairness, and equity be embodied in professional practice.

4.2.2 Engineering Culture Embedded in Organizations

Interestingly, engineering professional culture is often embedded in a corporate institution with a fiduciary duty to investors and its own institutional culture specifically designed to inculcate employees with the corporate values, beliefs and assumptions intended to create a sense of ownership and identification with the organization in order to motivate high performance and contribution alignment with the corporate goals. These values, beliefs and assumptions are also informed by historical institutional structures and cultures. Kunda [32] explores the roots, rhetoric and reality of embedded corporate engineering culture and argues "the development of strong corporate culture is the latest stage in the historical development of managerial ideology toward an emphasis on normative control - the desire to bind the employees' hearts and minds to the corporate interests." Kunda undertook an ethnographic investigation of the engineering division of a tech company regarded to have successful culture management. The company management carefully developed, articulated and disseminated organizational ideology and embodied it in the policies governing employees' work lives. Additionally informal policies and events were also engineered to maximize a sense of ownership and security and generate a commitment to the company in a member role [32]. Three classes of employees were identified with varying levels of influence and control: the top tier consists of full members who are the key participants and targets of cultural inculcation, the middle employee tier where there is some ideological skepticism accompanied by less stability and the lowest tier comprised of temporary workers, who are essentially disposable and subject to a different level of control. The study resulted in three specific concerns: culturally inculcated corporate control impacts professional and managerial employees escalating the conflict between commitment to the corporation and its definition of reality and individual professional and personal duties and responsibilities; the contribution of corporate power to the marginalization of those who are not in the top tier member role; and finally the impact of corporate power on society and the influence spread via inside interconnections within the corporate world and governments [32]. Moral identity and disengagement research has demonstrated this conflict can lead to unethical decision making and unprofessional behaviour [33] [34] and more specifically among engineers exhibiting pro organizational behavior [21].

4.3 Engineering Education Culture Change

4.3.1 Similarities and Differences - Engineering Education and Professional Culture

The embeddedness of engineering practice culture in government, regulatory and university institutional cultures results in similar concerns to a greater or lesser degree depending on the ideological culture and structure of the institution. Universities restructured to a more corporate model are more likely to reflect similar characteristics. What is clear from Kunda's work is institutional culture can influence societal or national culture. Kostova [35] presents a review and critique of institutional distance literature and describes three underlying theoretical foundations: organizational institutionalism, institutions are relatively stable social structures with regulative, cultural-cognitive, and normative elements; institutional economics, institutions structure human interactions with formal and informal rules; and comparative institutionalism, interdependent institutional arrangements in a given country. These theoretical foundations and the construct of institutional distance recognize the embeddedness of institutions in national culture and the necessity to manage cultural interactions between the institutions, especially across national boundaries. According to Hofstede, institutions impart value-laden "mental programs" that perpetuate the values on which they were founded within the same culture and may have different expressions of those values in other cultures. "Institutions cannot be understood without considering culture, and understanding culture presumes insight into institutions. Reducing explanations to either one or the other is sterile." [36]. The embedded and connected nature of engineering education and practice culture is illustrated in Figure 1 and our synthesis. In addition, we found key beliefs and assumptions prevalent in engineering education and practice cultures based on our literature review and observations and summarized them in Table 1.

4.3.2 Resistance and Levers for Change

These insights provide us with a deeper understanding of how engineering education culture and engineering practice culture are embedded institutionally and perpetuate founding values of the institutions (Table 1) and their home nation. The interactions shown in Figure 1 between the institutionally embedded engineering education, practice and regulatory cultures tend to reinforce the status quo with underlying cultural values of achievement, power, dominance, conformance, security and tradition being dominant. We can visualize how the influence of these values and associated underlying beliefs and assumptions such as meritocracy can extend to connections and interactions across similar functioning institutions (e.g., other universities and related institutions, corporate and regulatory institutions, international agreements recognizing professional credentials across boundaries, i.e., the Washington Accord. Attempting to understand engineering culture apart from the history and purpose of engineering, the connections between education, practice and regulatory cultures and the institutions they are embedded in is unlikely to yield a nuanced understanding of the core beliefs and assumptions and how they may be changed or may resist change. Institutional values are often linked with the home country values. As noted by Hofstede [36] "*Managers and leaders, as well as the people they work with, are part of national societies. If we want to understand their behavior, we have to understand their societies*." By extension, if we want to understand engineers and engineering culture, we need to understand the institutions they function in and the relationships between the institutions and their global context. Interestingly, with the Washington Accord and Western historical influences such as colonization and globalization, engineering education and practice share common aspects transcending national borders as observed by Godfrey [5] and represented in Figure 1 by institutions embedded within two interacting national societal cultures in the context of globalization (outer green region). The Washington Accord coupled with corporate and university globalization and the global mobility of engineers reinforces common cultural beliefs, values and artifacts of the embedded engineering cultures.

Interestingly, the values in Schwartz's model [27] associated with cultural openness to change and personal focus (stimulation, self-directed thought and action) are associated with the critical thinking and higher level cognitive and metacognitive skills associated with engineering leadership[[2], [3], [14].The values associated with social focus and self-transcendence (benevolence, humility and universalism) are often associated with ethical conduct and professional responsibility. These values are the levers for change in engineering education and practice. The beliefs that underly these values are not absent in engineering education and practice culture; however, their relative rank may be lower than the values associated with personal self enhancement (achievement, power, dominance) and social conservation (conformance, tradition, and security). These underlying motivational values are not opposing values, rather they are co-contraries that need each other in a similar manner that leadership and followership need each other to exist conceptually and as behaviours. The priority given to one pole of a co-contrary is learned and lived as cultural behaviors and artifacts. The shift in priority towards the other pole is both a lever for change and the resistance to change. Understanding the priority of self enhancement and conservation values in engineering education culture and practice allows us to examine the other pole of self-transcendence and openness to change and consider how to achieve balance.

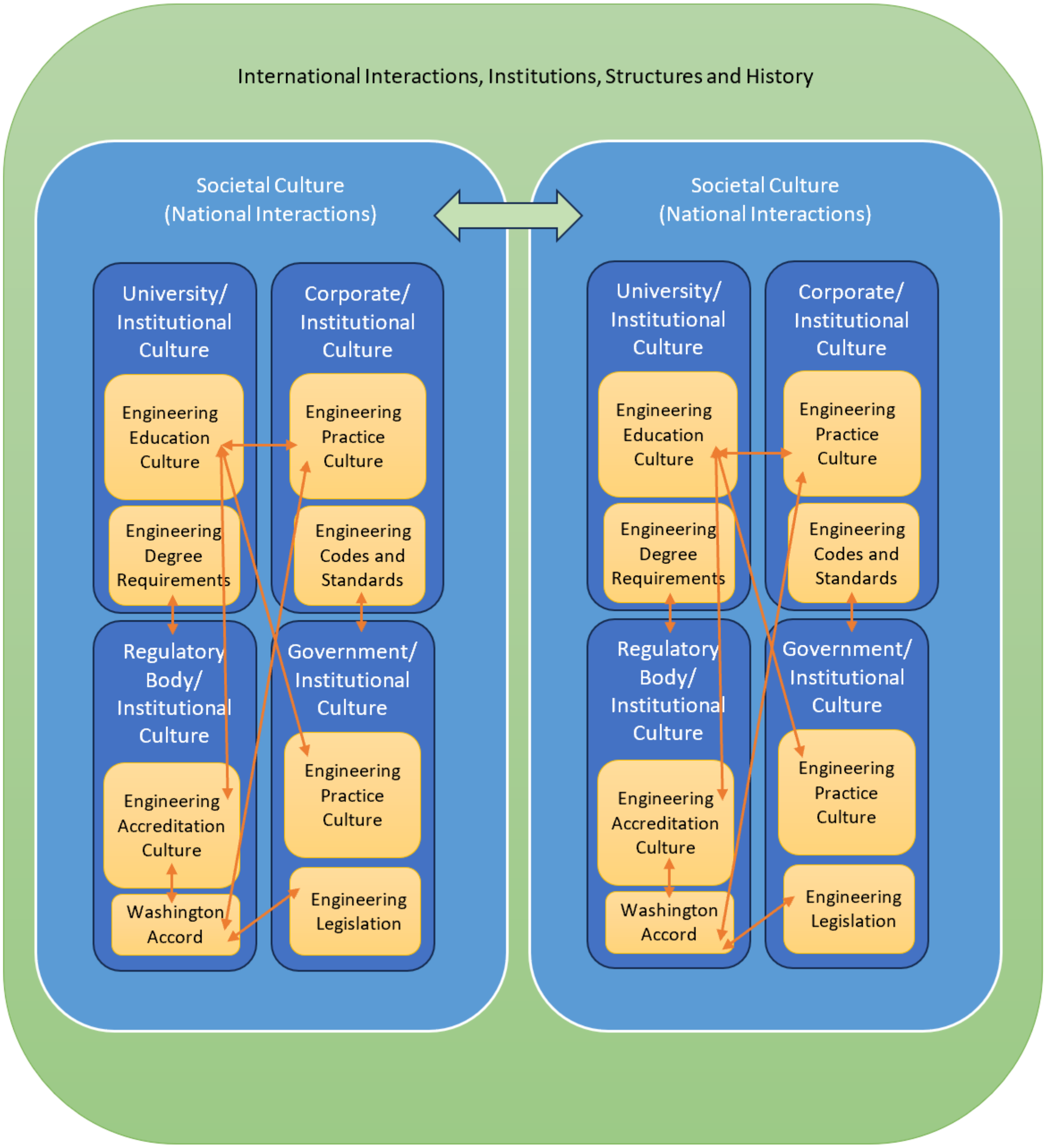

Figure 1. Cross cultural national and international interactions between engineering education and practice cultures embedded within universities, corporate, government and regulatory institutions.

Table 1. Underlying Assumptions and Beliefs Embedded in Institutional Culture.

Belief or Assumption	***Engineering Education***	***Institution University***	***Engineering Practice***	***Institution Corporation***
Meritocracy – Access (anyone can be an engineer)	Engineering is open to anyone who can achieve prerequisites	University is open to anyone meeting the entrance requirements and pay tuition	Member in training is open to anyone with an accredited Washington accord university	Employment is open to anyone with credentials and fit with position requirements
Meritocracy – promotion (but not everyone has the skills and abilities)	Success is based on students who work hard to understand the material and achieve high grades	Success is based on successfully meeting degree requirements	Success is based on people skills, problem solving and technical skills	Success is based on criteria of the institution, meeting the goals and targets, etc.
Difficulty and (Technical) Competence	Students require competence in math/science to be successful in their program	Minimum GPA – students meeting the minimum requirements are competent	Engineers need to be competent communicators team members and technically	Engineering work requires competent qualified engineers.
Motivation	Students require persistence to complete the program.	Degrees/ Credentials are awarded to those who complete the requirements	Engineers require persistence to address complex/difficult problems	Engineering work can require persistence perseverance and confidence.
Gender equality	Men and women have an equal opportunity to become engineering students	Men and women have an equal opportunity to become (engineering) students	Fewer women available to fill engineering placements	Fewer women available to fill engineering placements
Equity	All persons have an opportunity to become engineering students	All persons have an opportunity to become (accommodated) engineering students	All persons who graduate have an opportunity to become engineers	All persons with qualifications can apply. Hiring policies to address Diversity Equity and Inclusion
Responsibility	Accountable and responsible for meeting task requirements	Courses are offered on a semester timeline	Duty to protect the public and the public interest	Fiduciary duty to investors, duty to comply with regulations, etc.

4.4 Cultural Models and Dimensions
Schein's organizational culture model [37] describes culture as having three layers (Figure 2) with observable artifacts and behaviors being the top or visible layer; values and norms being below the surface layer and driving behavior; beliefs and assumptions being the deepest layer informing the values and norms of a social group suggesting the core beliefs and assumptions of a social group lead to the visible and observable expression of culture and the experience of that culture by individuals outside or new to the social group who may not yet know, understand or have adopted the shared beliefs and assumptions. A social group can be a religious group, a national group, an ethnic group, a gender group, a professional group, and as in Schein's model, an organization. Essentially a social group has characteristics of shared sameness and unity. Along with being shared, culture is commonly thought of as learned as it is based on beliefs and assumptions thought to be learned as an individual grows and develops values and practices. Consistent with Hofstede's description of levels of culture, these social groups can be embedded in larger social groups or structures and influence the expression of culture in the larger group and in turn be influenced by the culture of the larger social group. These levels can be compared to the embedded leadership spheres of influence described by Jamieson and Donald [2]: Individual, team, organization, and society. At each level shared beliefs, assumptions and values influence the individual and collective behaviours and shared artifacts of the sphere of influence.

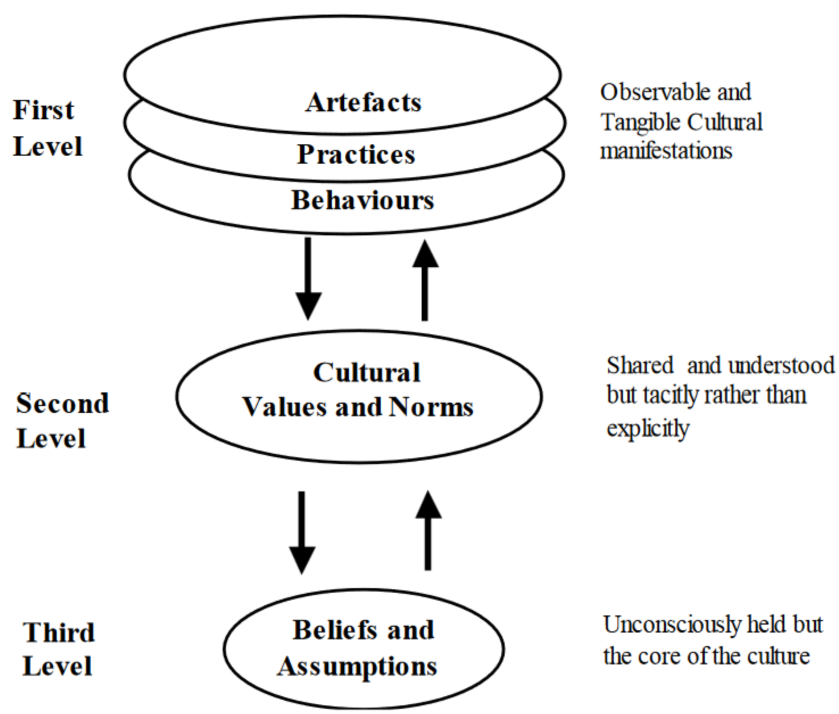

Figure 2. Godfrey (2009) [8] **adapted from Shein (1985)** [37]

Perusing the definitions of culture offered up by dictionaries and internet searches, culture is often described in terms of *shared* cultural practices and beliefs, which include aspects or elements of culture such as: language, symbols, ceremonies or rituals, knowledge, heroes, ideas, tools, institutions, an everyday way of life, ways of thinking, being, and knowing, attitudes, ordinary behavior, knowledge, meanings, religion, roles, etc. In other words, the aspects of culture describe the shared ontology and epistemology of a group of people who share common identifiable characteristics that define them as a social group. As these shared characteristics are not typically described as inherited traits [36], culture can be dynamic and it can change significantly over time if core beliefs, assumptions and values change. Some aspects of culture such as symbols, heroes, rituals and attitudes are more likely to change over time and as a result of generational and technological effects. Identifying the core beliefs and assumptions of a culture can be challenging. To study engineering education culture Godfrey [7], [8], [9], adopted Schein's model of culture as the theoretical framework in a descriptive study of engineering education culture at one institution (Figure 2). Godfrey developed a set of questions to interrogate epistemic values and ontological perspectives including: the way people within an engineering education institutional social group related to others internal and external to the social group, the qualities and characteristics necessary to fit and be accepted, and the prime objective of engineering education. From these questions and her observations over many years she developed what she terms six dimensions of engineering education culture: An engineering way of thinking, and engineering way of doing, being an engineer, acceptance of difference, and ways of relating in the social group and external to the social group [9].

As comparative dimensions, these areas are not well suited to cross cultural comparison as they are not easily measurable in a comparative or relative sense and are arrived at via descriptive aspects or elements of culture (Table 2). Some of the items described as characteristics of engineering education culture have changed or have begun to change over the years as a result of generational effects defining new behavioral norms while other aspects have persisted. The persistent aspects and artifacts are more indicative of the core values, beliefs and assumptions of engineering education culture and/or the institutional interactions that may impact engineering educators and influence their behaviour (i.e., research expectations) However, these cultural dimensions do not identify the underlying values, beliefs and assumptions of engineering education culture. Hofstede describes a cultural dimension as an aspect of a culture that can be measured relative to other cultures. ([36] p, 31) A dimension groups together a number of phenomena empirically found to occur in combination, i.e. trends that the phenomena occur together not whether they are logically related [36].

In Software of the Mind, Hofstede also describes layers of culture [36] as embedded in a national culture to which an individual may belong to including gender, generation, social class, organizational employment, and regional/ethnic/religious/ linguistic groups, changeable aspects of culture and the more persistent values and beliefs. A description of individual engineering identity development seems to be a different level apart from engineering cultural identity. The latter includes the intersection with other social groups, for example, gender, social class, professional status (student, in training, professional), and institutional social groups that influences the shared behaviour, values, beliefs, and assumptions of the larger social group of engineering education participants. The former, whether and how an individual develops an engineering identity are complex and encompasses the process of initiation into the culture and the acceptance or rejection of the cultural practices by the individual. Cultural transmission results from the interaction of an individual with other individuals who identify with that culture and the degree of acceptance of the observable cultural artifacts, values, beliefs and assumptions. It would seem that cultural transmission of the status quo would be associated with resistance to change and a critical examination of the cultural transmission of values and beliefs would be a lever for change. This critical examination and adoption of values and beliefs is associated with engineering leadership.

Table 2. Godfrey's cultural aspects and questions [7] mapped to Shein's model

Godfrey's Classification	***Cultural Aspect***	***Godfrey's Questions***
An engineering way of thinking	Knowledge, ideas; Unconsciously held	What kinds of knowledge are valued? What is perceived as truth? Is there a prevalent way of thinking? What constitutes reality?
An engineering way of doing	Rituals	How is teaching and learning accomplished? What do our practices tell us about our assumptions of the "right" way to teach/learn?
Being an engineer	Characteristics; Shared and understood tacitly	Are there attributes and qualities inherent in being "an engineer"? Who fits in and is successful?
Acceptance of differences	Attitudes, everyday way of life	How is difference accepted and valued?
External/Internal relations	Attitudes, rituals, everyday way of life; Observable and tangible manifestations	How do people relate to one another in this culture? What is our relationship to the rest of the university and academia in general, the profession, and the community?

4.5 Dimensions of Culture, Levels of Culture and Cultural Embeddedness (Hofstede)
Engineering education culture is embedded in a variety of university institutional cultures and engineering practice culture is embedded in a variety of corporate cultures. Both types of institutions are embedded in societal culture and connected with regulatory institutions (APEGA, PEO, Engineers Canada, etc.) also embedded in societal culture and connected to government institutions and international agreements. Engineering education culture does not exist as a monolithic entity; rather it exists as connected embedded cultures within educational institutions connected to professional engineering cultures embedded in corporate and entrepreneurial institutions. They are also connected to regulatory organizations and government legislation embedded in national and global societal levels as illustrated in Figure 1. Each of these levels of culture can be described by Hofstede's dimensions of culture and exemplified by co-contraries [1].

4.6 Hofstede's Dimensions of Culture
Hofstede originally described four cultural dimensions that can be used to categorize underlying core beliefs and assumptions at the country level. Hofstede grounded the work in prior work in anthropology and sociology with respect to culture (Table 3). Hofstede initiated this work after completing a statistical analysis on an IBM values questionnaire dataset he had access to. The data for similar types of IBM employees spanned multiple countries and four key clusters emerged. These clusters aligned with the common problems of social groups as identified by Inkeles and Levinson [38] and provided insight as to the impacts of national culture on a multinational corporation (IBM). Hofstede published the four dimensions in 1980 ([39]; [40]; [41]) . Hofstede developed a taxonomic classification based on anchored scales allowing for

relative comparison of cultures. Although social groups and countries may face common problems that need to be addressed for humans to live and work together, the solutions to these problems are many and grounded in the values, beliefs, and assumptions of the group and are reflected in the culture. In the analysis, Hofstede's original taxonomy consisted of four elements using anchored scales: power distance vs closeness, the extent to which power in a hierarchy is accepted; uncertainty avoidance vs acceptance, the extent to which uncertainty is tolerated; individualism vs collectivism, the extent to which autonomy is valued; and masculinity vs femininity, the extent to which masculine characteristics such as competition, achievement are valued compared to feminine characteristics such as cooperation and caring [36]. As further research progressed, two more dimensions were added later: Long term orientation (LTO) vs short term orientation (STO) identified by the Chinese culture connection study (1987) and Indulgence vs restraint, based on the world values survey [42]. LTO vs. STO was further developed using world values survey (WVS) data.

Table 3. Hofstede's original four cultural dimensions with respect to social group problems

Common social group problems	***IBM study statistical factor analysis results***	***Cultural Dimension Relative Scale***
Inkeles and Levinson (1954)	Geert Hofstede (1974)	Hofstede's original four cultural dimensions (1980)
Relation to authority	Social inequality, including the relationship with authority	power distance (from small to large)
The relationship between individual and society	The relationship between the individual and the group	collectivism versus individualism
The individual's concept of masculinity and femininity	Concepts of masculinity and femininity: the social and emotional implications of being born as a boy or a girl	femininity versus masculinity
Dealing with conflicts, including the control of aggression and the expression of feelings	Dealing with uncertainty and ambiguity, related to the control of aggression and the expression of emotions	uncertainty avoidance (from weak to strong)

4.7 Critiques of Hofstede's Dimensions of Culture

Although Hofstede's dimensions have been used in many studies, questions with respect to the uniqueness and the validity of constructs have been raised in the literature. An empirical factor analysis by Beuglisdijk and Welzer [41], found the latter two dimensions (indulgence vs restraint and STO vs LTO)to be a single dimension. The original data was IBM centric and the validity of some survey items defining the collectivism construct in individualism vs collectivism have been questioned. The original survey items appear to be more aligned with company orientation or individual development. The extension of the corporate based survey items to the construct of collectivism as an economic and political concept may lack validity. In addition, another criticism of Hofstede's taxonomy is that power distance and individualism as described by Hofstede are not distinct dimensions [41]. In their empirical analysis, Beuglisdijk and Welzer [41] found they are opposite poles of the same dimension. In addition, masculinity (competitiveness) vs Femininity (cooperation) was found to be associated with LTO vs STO and not independent. This reduction of the implications of being born as male or female (masculinity vs femininity) to competitiveness and cooperation or an individual orientation to succeed ignores the possibility a society or social group may have collective underlying beliefs, assumptions and values with respect to expectations for masculine and feminine roles (and inclusion or exclusion). Additionally, this reductive representation fails to consider the implication of a more inclusive conception of gender beyond male and female binary. There is a misconception this dimension is assigning a gender to describe a culture as either more masculine or more feminine making it politically incorrect when, in fact, it could uncover the beliefs and thinking that limit the roles of women and LGBTQ2S individuals in engineering. This dimension is intended to measure the collective thinking of a society or social group with respect to expected gender roles. For engineering education this a particularly relevant construct as the collective thinking about what women should or should not do or be able to do impacts how women in engineering are treated and the level of marginalization. Conflating expected gender roles and biases with cooperativeness vs competitiveness ignores the beliefs and assumptions with respect to gendered roles in a culture or embedded culture that may need to be addressed to effect real change. LTO and STO are associated with the collective beliefs of a society or a social group with respect to the role of government in addressing complex issues. STO is strongly associated with westernization or Americanization and the expected role of the market in addressing complex issues such as climate change, in other words economic growth is prioritized. LTO is associated with the expected role of government in addressing complex issues and having a future orientation consistent with the long-term well-being of the economy, society and the environment, in other words, sustainability is prioritized.

Beuglisdijk and Welzer's empirical observations collapse Hofstede's six dimensions to three: power (hierarchy/authority) vs individualism (autonomy); uncertainty avoidance vs acceptance; and long term orientation (restraint) vs. short term orientation (indulgence) and were renamed by Beuglisdijk and Welzer as Collectivism vs Individualism, Distrust vs trust, and Duty vs Joy [41]. These three dimensions are ontological in nature and describe aspects of the way of being in a culture, however, this reduction ignores the relation of cultural dimensions to the way a social group addresses common problems as described in Table 3. For example, collapsing power distance with collectivism vs individualism collapses the individual's relationship to authority with the relationship to the group which are fundamentally different conceptually.

Beuglisdijk and Welzer's first dimension describes the cultural acceptance of collectivism and the individual without considering the individual's relationship to power/authority. This reduction does not seem to account for the reality that collectivism or individualism may be imposed based on the underlying beliefs, values and assumptions inherent in the societal institutional structures as dictated by those in power. In other words, the two dimensions are related in the sense that a society with large power distance may dictate the relationship of the individual to society with respect to collectivism and individualism, i.e., freedoms limited by authority and a smaller power distance may empower individuals with a greater voice.

The second dimension describes the ontological perspective of the world as a place of fear and where bad outcomes can happen (distrust, risk, lack of control or influence, etc.) contrasted with the perspective of the world as a place that can be managed and outcomes can be managed (trust, risk reduction, flexibility of response). This dimension appears to be consistent with Uncertainty avoidance.

The third dimension describes the ontological view of the world as a place where delayed gratification and planning are required to ensure survival and requires planning, i.e., food needs to be stored in times of plenty for times of scarcity, in contrast with the view of the world as a place where food needs will be met so life can be enjoyed now.

Collapsing LTO vs STO with Indulgence vs restraint essentially collapses the societal beliefs with respect to individual restraint of natural desires for enjoyment with the collective beliefs with respect to long term decision making and the evaluation of the impact of consequences on the social group and environment. Although there may be similarity between these two constructs, they are conceptually different. The challenges of understanding the underlying beliefs, assumptions and values of a social group when reducing the cultural dimensions as suggested by Beuglisdijk and Welzer are captured in Table 4. The conceptual discrimination provided by Hofstede's six dimensions is useful in understanding engineering education and practice cultures as it allows us to interrogate the underlying beliefs and assumptions inherent in engineering education and practice cultures about individuals and the larger social group.

Table 4. Challenges with Beuglisdijk and Welzer's Proposed Cultural Dimension Reduction

Underlying Belief, Assumption or Value	*Hofstede (2010)*	*Beuglisdijk and Welzer (2018)*
The societies relationship to authority, i.e. the influence an individual may have on societal rules and decision making	power distance (from small to large)	Collectivism vs Individualism
The relationship between the individuals and society	collectivism versus individualism	
Dealing with conflicts including the control of aggression	uncertainty avoidance (from weak to strong)	Distrust vs Trust
The concept of femininity vs masculinity and the expectation specific tasks and roles will be fulfilled based on gender	femininity versus masculinity (values, beliefs, and assumptions with respect to gender-based roles or lack thereof)	Femininity is equated with cooperation and masculinity with competitiveness
The time horizon related to orientation and attitudes of the society with respect to the role of government in directing the responsible use of resources. Sustainability vs. Exploitation	Long term orientation vs short term orientation	Duty vs Joy
The belief that individuals should be able to gratify a natural desire to enjoy life and have fun vs the belief that these desires should be curbed.	Indulgence vs restraint	

4.8 Measuring Cultural Change in the National Context

Political scientists Inglehart and Welzel described national/societal cultural change in the context of a defined geographical area as having two value-based dimensions. The first dimension is anchored by the two poles of traditional or secular societal values. Traditional values encompass a religious worldview, deference to authority, emphasizing traditional family values and long-term commitments, i.e. marriage and parent child caregiving roles and responsibilities. Divorce, euthanasia, abortion, and suicide are typically rejected. Secular values encompass the opposite pole, placing less emphasis on traditional values and authority and embrace a rational perspective with more tolerance for divorce, euthanasia, abortion, and suicide. The second dimension is anchored by the two poles of survival (duty) and self-expression (personal freedom). Survival values emphasize economic and physical survival and there is an element of ethnocentricity. Self-expression values emphasize tolerance and acceptance of different social groups and their beliefs and values. There is a desire for more participation in economic and political aspects of the society/nation. The measurement of each dimension is based on 5 indicators that remained consistent over time. These measurements indicate where a country falls on their map delineated by the two dimensions. Interestingly, the dimensions for a set group of countries were mapped over nearly 40 years and the placement of countries changed with respect to three key factors, economic development, generational effects, and geopolitical history.

Hofstede thought culture to be relatively stable over time [36]in contrast with modernization theory where dynamic changes in norms and values can be predicted based on economic development. Inglehart and Welzel hold that self-expression and autonomy replace self-restraint and obedience as economic development proceeds [43], [44], [45] in other terms there is a progression from Duty to Joy or from LTO to STO. In addition, the geographic location and history of a country were found to influence the predicted changes based on economic development [46]. Beuglisdijk and Welzer [41] conclude cultural change is driven by economic development, generational effects, and the unique geopolitical history of a country. These three factors influence cultural change over time with the first two factors accounting for about half of the changes. As the latter has strong influence the relative country rankings remain relatively stable as cultural change is driven by economic and generational effects. With respect to the embedded nature of engineering education and practice culture, this underscores the cultural connection of engineering to economic development, an observed shift from traditional sustainability to exploitation and development, and potentially a shift towards more open self-expression.

5. Summary

Engineering education and practice culture are not monolithic yet they share common observable characteristics and artifacts. A reductionist examination of engineering education culture excluding the embedded nature of engineering education in an institutional culture and cross institutional interactions within the national culture and aspirational framework is unlikely to yield the underlying beliefs, assumptions and values contributing to the underlying beliefs, assumptions and values of engineering education culture and possibly contributing to a resistance to change. Engineering education culture and engineering practice culture are linked yet distinct as they are embedded in different institutions with different objectives and regulated by related but distinct organizations with a relationship to an international governing body. In addition, the influence of institutional culture on the embedded culture cannot be ignored. The underlying systemic beliefs, assumptions values and the resultant institutional power structure of a society, i.e., government, result in the creation of the cultural and regulatory environment that institutions, i.e., universities and corporations, function within and by extension the cultures embedded in the institutions.

Engineering education culture prepares graduates to accept particular elements and expectations of engineering practice culture, and both are informed by institutional and societal cultures. Engineering students tend to embrace meritocratic beliefs along with personal enhancement and conservation values. In essence engineering education prepares engineering students for responsible followership in a corporate economic system, to follow good engineering practices and problem solve, to follow established systems, regulations and procedures. However, the limited focus spent on engineering leadership and professionalism values and beliefs may leave engineering graduates vulnerable as the emphasis on followership and identification with institutional and organizational values, beliefs and assumptions are implicitly transferred. An embedded engineering education culture must function within the university institutional culture and serve the requirements of the institution while ensuring graduates remain relevant to the needs of corporate, government and regulatory institutions. Corporate and University cultures function within the societal institutional structure and culture. As a result, engineering education culture will necessarily reflect the national and institutional cultural dimensions it operates within and the underlying beliefs, assumptions and values. The levers for change identified include a stronger focus on engineering leadership and professional skill development in the curriculum, specifically those that embrace the values of self-transcendence and personal openness to change.

6. Next Steps

Identifying the influence of societal and institutional cultural dimensions on engineering education culture will enable us to better identify the underlying beliefs, assumptions and values that inform the thinking and behaviours observed in engineering education culture. In our 2023 paper [1] we explored the potential for using Hofstede's cultural dimensions as a lens that could provide useful insights with respect to cultural tensions associated with the beliefs, assumptions and values that manifest as the observable aspects of engineering education culture. In this paper we have attempted to explore and characterize the underlying relationships between engineering education and engineering practice cultures with institutional and societal cultures to enable the identification of embedded cultural dimensions and underlying values and beliefs in the context of engineering education. The next step is to leverage these ideas and connections to help identify barriers, mechanisms and motivating factors for incorporating engineering leadership and professional education more broadly in the engineering curriculum. It may also be leveraged to prepare both engineering graduates and faculty with an awareness of where the existing engineering education and practice culture might be a barrier to the needed changes required for the profession to address the increasingly complex socio-enviro-technological challenges.

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