Chapter 10
The Impact of Culture on Engineering and Engineering Education

Adam R. Carberry and Dale Baker

10.1 Culture and Engineering

A culture is the result of symbolic elements shaped by the given system within which they are created, distributed, evaluated, taught, and preserved (Peterson and Anand 2004). The discussion of culture in this chapter holds many different meanings based on various lens used to discuss cultural impacts. Whether intentional or not, the actions of those in the field of engineering have established a culture that differentiates engineers by how they think, do, relate with others and the environment, accept difference, and identify as being an engineer (Godfrey and Parker 2010). Practice of these cultural dimensions is a major influencer of how the field is perceived to those looking in from the outside. The perception of an engineering culture is connected to the discipline and how engineering institutions and industries conduct business. This lens discusses how individuals perceive the field and how they see themselves fitting in with the established culture. The perception of the field and how individuals view themselves as fitting in is especially germane to efforts that increase the participation of women in engineering, which has historically been a male-dominated field with its own brand of masculine culture. Perception of the field also influences how engineering is taught and how western engineers work in non-western cultures. Engineering is also a discipline that aims to serve society. As such, the established culture of the given society being served has impacts on how engineers go about solving problems. This lens recognizes the

A.R. Carberry (✉)
Ira A. Fulton Schools of Engineering, The Polytechnic School, Arizona State University, Mesa, AZ, USA
e-mail: Adam.Carberry@asu.edu

D. Baker
Mary Lou Fulton Teachers College, Educational Leadership and Innovation, Arizona State University, Tempe, AZ, USA

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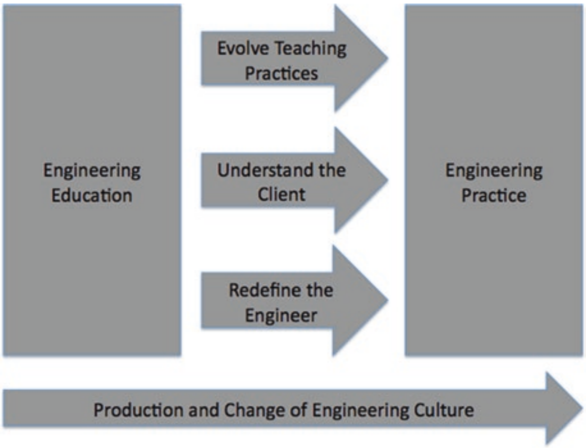

Fig. 10.1 Schematic overview of the impact of factors discussed in the chapter

importance of the user/client and how their culture can impact the design of a solution.

The broad scope used in this discussion is intended to provide a general description of how culture impacts the engineering field as a whole. The following sections will break down this discussion to investigate perception, production, education, society, enculturation, and the implications of these factors on engineering and society to provide recommendations for educators, learners, and practitioners. Figure 10.1 depicts how engineering education must evolve teaching practices, stress the need to deeply understand clients, and redefine who engineers are and what they do to produce and change the engineering culture that exists in practice and is perceived by society.

10.2 Perception and Production of Engineering Culture

A key indicator of an established culture is public perception. A society's perception of a given context reflects their understanding as a summation of experiences and interactions with the given context. Encounters can range from firsthand mastery experiences to simple word-of-mouth information. Engineering is a body of knowledge that the majority of the public has never had the opportunity to formally learn or experience. This is evident by evaluations that clearly suggest an overall lack of awareness and understanding about engineering and what engineers do. Marshall et al.'s (2007) assessment of public attitudes and perceptions of engineering and engineers in Great Britain revealed a degree of confusion and uncertainty about the discipline. Respondents associated engineering only with fixing things, providing things people rely on in their everyday lives, and causing key problems in society (e.g., climate change). The National Academy of Engineers' (1998; later update in 2002) assessment of public perceptions in the United States added that Americans were generally uninformed about engineering and viewed engineering as simply the application of science. Engineering as a discipline doesn't have to search any further than itself as being a major culprit to blame for the public's lack in understanding about the field. Cultural norms established by the field from Australia and New Zealand to the United States and throughout Europe portray engineering as boring and masculine (Hansen and Godfrey 1997; McLean et al. 1997; Sagebiel and Dahmen 2006; Tonso 1996).

Western society has adopted a culturally influenced notion that engineering drives innovation and technology and fosters entrepreneurship (Nazan and Bogers 2015; Vickers et al. 2001) through ABET-accredited programs that educate students in applied sciences, computing, engineering, and engineering technology. A major contributor to the notion that engineering is boring and only for men is the established reputation of engineering being a highly complex field fit only for those who excel in mathematics and the "hard" sciences (e.g., physics, chemistry, and biology). This notion is propagated through media outlets that push a pervasive image of what engineering and engineers look like. For example, automobile company commercials often have engineering in their slogans (e.g., Ford: "Engineered that lasts" or Audi: "Truth in Engineering") leading to the perception that complex machines such as automobiles are equivalent to engineering. Engineering program websites also tend to project a certain image of what an engineering student should look like. Television shows portray how people view the field both positively and negatively (Tang 2013). For example, shows like *Design Squad, Engineering Marvels, Extreme Engineering, Epic Engineering, How it's Made, Engineering Disasters*, and *MythBusters* portray these fields in a positive light; however, many may find these shows boring to watch or even frightening to think about the catastrophic failure that can result from poor engineering. Additionally, shows like the *Big Bang Theory* make it appear as though only nerdy super geniuses can be successful in science and engineering. These media representations can be very influential on public opinion and interest in engineering as demonstrated by research asking children to "Draw an Engineer" (Capobianco et al. 2011; Ganesh 2011; Knight and Cunningham 2004). Students think about engineers as using tools to build and fix car engines, designing things such as buildings or machines, or someone who drives and/or works with trains. Drawings also indicate that students think engineers are mostly men. The established masculine culture of engineering has helped to propagate these notions resulting in a perpetual cycle that recruits and retains only those who fit the established cultural mold.

The large quantitative survey analyses (Davis and Gibbin 2002; Marshall, McClymont and Joyce, 2007) and complementary qualitative workshop polling (Marshall, McClymont and Joyce, 2007) provided a broad view of the general public's perception of engineering culture. Additional qualitative analysis of young children's drawings (Capobianco et al. 2011; Ganesh 2011; Knight and Cunningham 2004) provided a full picture of how society – youth to adult – perceive engineering. These findings should be alarming to those in the field of engineering and those who seek to recruit and retain a diverse population of future students. The broad conclusions suggest that efforts being made to change public perception need to either be rethought or expanded to reach a greater percentage of the general public. The solution to a well-informed society is through improved education. Citizens need to be educated on what engineering is and what engineers actually do as early as middle school to grow interest and understanding (Zunker 1994). Current educational practices are clearly falling short on projecting an accurate depiction of the field, which is heavily influenced by the masculine culture established within traditional engineering education programs.

10.3 Engineering Education Culture

10.3.1 Traditional Engineering Programs

The culture of engineering schools is reflected in instructional approaches that influence learning, metacognition, interest, and teaching. Research by Nelson Laird, Shoup, Kuh, and Schwarz (2008) found that engineering faculty were less likely to engage in instructional practices that encouraged deep learning than in what they called soft applied fields. They attribute this difference to disciplinary socialization and a culture of consensus in the content and methods of inquiry, which they state do not exist for soft fields. Brint et al. (2008) also conclude that the academic culture in engineering may discourage the development and implementation of experiences that promote the use of deep approaches to learning. Brint, Cantwell, and Hanneman describe the culture of engineering as one that rewards:

> *…industrious, but unimaginative students who perform technical tasks competently but express little initiative outside of required activities and little interest in connecting ideas or interacting with their professors. Interaction between students and faculty and participation in class are minimal, and interest in jobs seems to greatly outweigh the inspiration of ideas.* (p. 398)

Brint, Cantwell, and Hanneman did not expect to see many changes to engineering in the future. The established culture of engagement, where students participate in class and are interested in ideas, is perceived by faculty to be more appropriate for majors in the arts, social sciences, and humanities rather than science and engineering. It is no surprise then that Finelli et al. (2014) found 60 % of the engineering classes they observed to lack any form of active learning.

Boiarsky (2004) describes the culture of engineering education as narrowly focused on content that does not teach students how to learn-to-learn. Bucciarelli, Einstein, Terenzini, and Walser (2000) also have an unflattering description of the predominant engineering culture. They describe it as "… based on compartmentalization of knowledge, individual specialization, and a wholly research-based reward structure" (p.141). The lecture format also creates a barrier between professors and students that results in lower self-efficacy, academic confidence, and GPA among students (Blinkenstaff 2005; Vogt 2008.). Students in large lecture format classes are also more likely to rate instruction poorer than students in smaller classes (Johnson et al. 2013).

A case study of engineering culture in a high ranking engineering school in New Zealand found faculty describing their teaching as learning the hard way to cover material through traditional lecture-based courses. Problem solving was taught using a reductionist method with an emphasis on mathematics (Godfrey and Parker 2010). Godfrey and Parker emphasize the mathematical and learning the hard way culture of engineering by quoting a student who repeated a well-known joke to them. He said “You know you’re an engineer if you haven’t got a life and can prove it mathematically” (p. 10).

Montfort et al. (2014) feel that faculty epistemological beliefs are at the heart of the difficulties in bringing about reform and educational innovations in teaching engineering. For example, the belief that the natural world is too large and complex results in an absence of real-world examples and de-contextualization of concepts. Personal epistemologies are also relied upon to determine which questions, issues, or opinions to address in courses. These choices by faculty impact the beliefs students bring to their future studies and further on down the road in their careers (Carberry 2014). Montfort, Brown, and Shinew concluded that questions and issues that are unaddressed could have an impact on students’ continuing interest and retention in engineering.

10.3.2 Teaching Methods in Engineering Education

Although many engineering professors are aware of and respect the research on learner-centered teaching, they are reluctant to adopt these instructional strategies because their institutional culture rewards research productivity and high-level professional activities (King 2012), while discouraging high levels of effort to improve teaching (Crawley et al. 2007). Other faculty members do not embrace pedagogical reforms presented with strong evidence of effectiveness because they are unwilling to invest the time to teach the course using new techniques to replace teacher-centered approaches. The primary reason for this reluctance is that the time commitment to learn and use innovative pedagogies is greater than for traditional lectures (Fairweather 2008). Reluctance to adopt pedagogical reforms may also be due to little or no training in how to teach. One junior faculty interviewed by Godfrey and Parker (2010) said in reference to teaching, “… you are just dumped into the job – there is no real preparation beforehand” (p. 13). Faculty lack the education and, as Graham (2009) found of faculty in the United Kingdom, confidence to design and use assessments to evaluate learner-centered practices such as project-based learning activities.

New engineering faculty are essentially “well intentioned gifted amateurs” who need to develop expertise, which requires commitment, time, focused resources, and recognition in the institutional reward structure (Ambrose and Norman 2006). Fairweather (2008) notes that the more time a faculty member spends on teaching, the lower their salary, while the more time spent in research and publications, the higher their salary. Institutions of higher learning valuing teaching can therefore be viewed as merely rhetoric. King (2012) sees the problem differently suggesting poor alignment between those who would benefit from changes in engineering curricula and instructional pedagogy (e.g., students and the public) and those who have influence over whether change will take place (e.g., faculty). It may actually be engineering professors who do not foster change who are contributing to retention problems in engineering majors.

This notion is supported by students who transfer out of engineering majors citing poor teaching and advising as a primary cause (Marra et al. 2012). Students in the Marra et al. (2012) study put it thusly: "…and the professors didn't seem to care at all whether or not people did well in their class" and "The advising system was very poor. I was a number not a name. The first two years are when students most need advising…we had advisors who basically told you to just follow the rubric in the engineering manual" (p. 18).

Institutional culture, the culture of the university in which the engineering program resides, also has an impact on engineering students. Seymour and Hewitt (1977) in their landmark study found that institutional culture influenced students' decision to switch from an engineering major to other majors. Tonso (2007), studying a reform curriculum of design in engineering, found that the masculine campus culture of an engineering school made women feel invisible and like outsiders negating the effects of the experiential curriculum design to bring women into engineering. Marra et al. (2012) also found that one of the factors leading to dropping out of an engineering major was an engineering culture that made students feel like outsiders.

It is not just a culture that rewards research activities over teaching that has a negative effect on students. Women, and in particular women of color, find the competitive culture of engineering detrimental to their success (Godfrey and Parker 2010; Johnson 2007). Cultural change is needed in order for the discipline to evolve and grow.

10.3.3 Changing the Culture of Engineering Education

Understanding the existing culture established within engineering or perceived by the public is essential to informing change. It is clear that engineering needs to be more engaging, relevant, and welcoming (Clough 2004) and that such change must be driven by engineering faculty and administrators (Jamieson and Lohmann 2012); but change is difficult for both people and institutions. Change in engineering, according to Graham (2012), comes about only when there is a shared purpose among faculty and agreement that change is imperative. McKenna et al. (2014) note that considerable work in reform has taken place at the local level by individuals or teams to change pedagogy or curriculum, but that these reforms have not had an impact on engineering culture at large. Furthermore, despite many reports about what engineering education should look like, there is little information about how change in the engineering culture can come about (Besterfield-Sacre et al. 2014). Besterfield-Sacre et al.'s analysis of the data from *Innovation with Impact* (Jamieson and Lohmann 2012) indicated that faculty, chairs, and deans felt that transformative change could come about through developing and disseminating innovative pedagogy, support for the scholarship of teaching, and implementing policies that supported and rewarded innovative pedagogy. Conspicuously absent in terms of the mechanisms to bring about reform was developing a shared vision and strategic planning for changing the culture of engineering. Godfrey (2014) suggests "…that change at the levels of curricula, structures, and behaviors is not sufficient for sustained cultural change. Cultural change requires transformation – forming new collective understandings and creating new beliefs about what is valued in engineering education" (p. 452). So what then can drive such a transformation? Graham (2012) found that motivation for reform, most often project-based learning, came from a school or college's position in the marketplace (70–80 % of the time). In contrast, project-based learning was implemented only 5–10 % of the time, even in schools and departments where a culture of innovation already existed.

There are better and stronger arguments for using a variety of student-centered experiential pedagogies than market place positioning. Engineering programs and curricula that reflect a culture that has embraced experienced-based teaching methodologies and student engagement are more likely to result in students using deeper approaches to learning (Chen et al. 2008; Shawcross and Ridgman 2012) in addition to traditional reading and studying (Kuh et al. 2004). Faced with numerous choices, faculty members are more likely to use just one research-based instructional strategy than they are to use two or more. From among the many effective pedagogical strategies, faculty are most likely to use case-based teaching, just-in-time teaching, and inquiry strategies (Borrego et al. 2013). Moderate levels of strategy use were found for think-aloud-paired problem solving, cooperative learning, collaborative learning, problem-based learning, and think-pair-share. The lowest level of strategy use was found for peer instruction and service learning. Strategy use by faculty contrasts the most commonly used student-centered instructional strategies of design projects and service found in most engineering curricula. Fisher et al. (2005) found that instructional reforms in engineering service courses improved ABET-related student learning outcomes in problem solving and analysis of complex problems. These strategies support the development of engineering expertise, but have not yet been rigorously tested for impact on learning (Litzinger et al. 2011).

10.3.4 Methods and Tools for Investigating Engineering Education

The studies cited describing engineering education culture used a variety of methods that allowed us to come to conclusions, make recommendations, and identify implications. These studies included:

- Thought-provoking pieces or position papers grounded in broad and interdisciplinary research studies (Ambrose and Norman 2006; Choresh et al. 2009; Clough 2004; Jamieson and Lohmann 2012; King 2012)
- Large-scale literature reviews with a synthesis of the findings and recommendations derived from the synthesis (Blinkenstaff 2005; Fairweather 2008; Litzinger et al. 2011; McKenna et al. 2014)
- Recommendations for reform drawn from existing literature and firsthand personal teaching (Boiarsky 2004)
- Information gained through a workshop (Bucciarelli et al. 2000) used
- A developed model for conceptualizing student engagement in engineering (Chen et al. 2008)

The referenced studies used a variety of quantitative and qualitative research methods. Most quantitative studies used survey data from a variety of instruments (e.g., National Survey of Student Satisfaction, Faculty Survey of Student Satisfaction, self-efficacy assessments, self-reports, and opinions) with statistical analysis of the data (Besterfield-Sacre et al. 2014; Borrego et al. 2013; Brint et al. 2008; Kuh et al. 2004; Marra et al. 2009; Nelson Laird et al. 2008). For example, Johnson et al. (2013) used student evaluations of the course and instructor and subjected them to statistical analysis to identify issues with teaching. Qualitative studies used case studies (e.g., Graham 2009), large-scale ethnographies (e.g., Godfrey & Parker, 2010; Seymour and Hewitt 1977; Tonso 2007), or interviews (e.g., Graham 2012; Johnson 2007; Montfort et al. 2014). There were also a number of studies that used a mixed methods approach. Examples include the RTOP based on classroom observations and factor analysis (Piburn et al. 2000; Sawada et al. 2002), institutional change plans and identified student learning outcomes using focus groups and surveys (Finelli et al. 2014; Fisher et al. 2005), and qualitative and quantitative techniques used to examine skill development in an engineering master's program (Shawcross and Ridgman 2012).

The various studies and approaches to analyze engineering education have shown us that an environment where students are engaged in deep thinking will require professors to change the way they teach, interact with students, and revise the curriculum (Brint et al. 2008). First and foremost, there should be more active learning. This includes (1) more class discussions about readings and ideas encountered in class and readings, (2) group work on projects in class and outside of class, (3) community-based projects, and (4) opportunities to tutor other students about course material. Professors will have to provide more, prompt formative feedback during the semester for all active learning activities. Other strategies to increase deep learning include internships, senior capstone projects, electronic discussions boards, and learning communities.

Coursework should be academically challenging and require effort. Students should be required to write papers that exceed 20 pages and engage in other activities that require analysis, synthesis, and the application of knowledge to novel problems and situations. The nature of teacher–student interactions will have to become more personal so that students can discuss career options, grades, and assignments with professors as well as engage in research projects with their professors.

The leadership of engineering schools needs to communicate how important good teaching and student relationships are for student success and that efforts in this regard will be valued and rewarded. Teaching must be evaluated in a more rigorous and systematic way with items that reflect changes in teaching using instruments such as the Reformed Teaching Observation Protocol (RTOP) (Piburn et al. 2000; Sawada et al. 2002). Leadership must facilitate changes by providing opportunities for professors to learn about effective pedagogy as well as opportunities to learn and discuss the research stemming from the learning sciences about the nature of knowledge and how individuals create it.

For all teaching situations, time, effort, and money should be put into smaller class sizes that allow discussion, professor–student interactions, and a studio model rather than a lecture model of instruction. Interdisciplinary courses should be developed that reflect real-world and interesting contexts. Students should also be provided with better advising, and student academic support should be provided so that students feel cared for as individuals and where they can get help without fear of negative consequences from professors or peers.

As a new field of study intent on improving the preparation of engineers, it is not surprising that the citations mentioned and the results presented in this section of the chapter reflect a synthesis of research from many disciplines that form the basis of reform recommendations. Engineering education scholars are also engaged in their own studies of engineering using a full complement of inquiry tools that will enrich our understanding of engineering education as a discipline and contribute to our understanding of how best to educate future engineers.

10.4 Societal Culture and Engineering: Beyond the Western Culture

According to Bernard Amadei, "Engineers have a collective responsibility to improve the lives of people living around the world" (Amadei 2004, p. 24). He notes that technical aspects of an engineering project are less important to success than cultural, social, economic, environmental, and ethical considerations. He also states that engineering schools are not adequately preparing engineers to think beyond the technical; except in rare instances where service learning is integrated throughout a curriculum (Duffy et al. 2011), faculty from different countries collaborate (Dori and Silva 2010), or pedagogical approaches like product archaeology are used (Ulrich and Pearson 1998; Lewis et al. 2010, 2011). Consequently, engineering graduates from western universities are often unaware of the cultural factors that have an impact on the transfer of technologies to non-western societies and the developing world. Many assume that it is as simple as providing the technology or borrowing technology and expecting that it will be successfully used anywhere (Kedia and Bhagat 1988).

Technology transfers are influenced by societal culture, organizational culture, and strategic management processes. Culture is least important to successful technology transfer when the technology transfer is from one industrialized nation to another and most important to success when the technology transfer is from an industrialized nation to a developing nation (Kedia and Bhagat 1988). Many factors influence technology transfer and adoption, which makes it problematic. The first issue to consider is whether the technology is appropriate. The topic of technology appropriateness to a given population and culture is not currently addressed in most engineering curricula or research because it is perceived as low tech and unimportant (Amadei 2004). Engineers must develop the skill of identifying when a technology is appropriate by learning how to assess benefit, resources, and knowledge to sustain technology, local conditions impacting success, user needs, government and other agency support, and cultural beliefs (Bhatia 1990; Sas 2011). In addition to these considerations, cultural factors such as avoidance of uncertainty, power distance, individualism versus collectivism, masculinity versus femininity, and abstractive versus associative characteristics must be taken into account (Kedia and Bhagat 1988). Engineers must develop listening skills to address these considerations because, according to Parsons (1996), engineers make contributions to developing countries "when the engineer truly listens to the desires of those he/she is attempting to serve" (p. 170).

10.4.1 Examples of Success and Failure of Engineering Projects

There are a plethora of wonderful examples illustrating the success and failure of engineering projects and curricula beyond Western civilization (Sas 2011). The data about engineering in developing countries was limited both in scope and methods. Unlike some other areas we explored in this chapter, there were fewer articles in engineering education journals and a greater concern for technology diffusion than the education of future engineers.

In India, the choice of which reusable energy technology to introduce depends upon the circumstances of the farmer. A study of the introduction of renewable energy sources found that a biogas engine for farming worked best for a relatively large farm where the farmer raises two crops a year and has capital and livestock to run a biogas plant. The farmer must also have knowledge of operating and repairing diesel engines and electric motors. In contrast, wind power or solar power requires less technical knowledge making it more successful and appropriate for a marginal farmer who brings produce to a local market (Bhatia 1990).

Improvements in agriculture in Africa have been difficult due to cultural perceptions of the role of agricultural engineers. Locally trained agricultural engineers have had limited success in increasing food production because of the perception that agricultural engineers are either farmers or tractor mechanics (Mafe 2005). The misperception of what agricultural engineers do and the lack of interest in agricultural engineering as a career choice are, in part, due to the curriculum in African universities. The curriculum has been adopted wholesale from developed industrialized countries, and students are not being prepared to create endogenous technologies that reflect the local needs (Adewunmi 2008).

In Pakistan, culture influences the education of engineers as seen in teamwork dynamics and the team roles individuals prefer to undertake. In particular, students take roles that resemble traditional Pakistani family dynamics. The discomfort with change and comfort with traditional practices limit the number of students willing to undertake team roles that foster creativity and stifle creativity. The university curriculum reinforces this problem by limiting course work to basic science rather than courses that foster problem solving and creativity (Hassan et al. 2014).

A project to construct houses and a water system in Nicaragua was deemed a failure because 2 years after construction the houses were in disrepair and the water system was not in use. The project failed for several reasons, including cultural factors such as (1) no money or expertise to fix the broken water pump and no means to transport it to be repaired, (2) no input to the project from members of the community about their desires or needs, and (3) high illiteracy rates and lack of knowledge among the community members about how to govern themselves as members of a cooperative overseeing the water system. In contrast, a similar project to bring drinking water to people in Nepal was successful because technical advice, a budget for skilled labor, and materials were provided by a local committee that managed the project. The local committee also provided the unskilled labor and was responsible for maintaining the system and buying spare parts available in the local market as needed (Parsons 1996).

The case of information technology transfer in Arab countries such as Saudi Arabia and Kuwait is another interesting case. They are developing countries, but money and education are not constraints. Cultural beliefs have been seen to be predictors of IT transference. For example, Arabs prefer to deal with people face-to-face, build consensus, build family-like environments in the workplace, and have a more relaxed sense of time. These cultural factors mitigate against technologies such as email and the use of online meeting places (Straub et al. 2002).

10.4.2 Know Your Client

The literature that supports the conclusions about societal culture and engineering came from a variety of sources using a limited number of methods. Three authors used literature reviews to advocate for a particular position and make recommendations for the developing world (Adewunmi 2008; Amadei 2004; Mafe 2005), while two other authors used literature reviews to develop a conceptual model of technology transfer (Kedia and Bhagat 1988). Two authors took the case study approach to examine engineering projects in developing countries (Bhatia 1990; Sas 2011). Parsons (1996) used the research literature to inform her interviews and then used qualitative analysis of the interviews and the literature review to support her recommendations about engineering in the context of the developing world. Straub et al. (2002) used both qualitative and quantitative analyses to examine the transfer of technology in the Arab world, while Hassan et al. (2014) used simple percentages to analyze survey data about national and engineering culture on team role selection.

These examples provide context for the reality that a community's culture has grave influences on whether or not a developed solution, particularly one involving technology, has the potential for success. An ideal solution for one community may not have success in another. For example, the rocket cookstove designed to reduce smoke and subsequent smoke-related health issues is for all intents and purposes an ideal solution; yet some villages that have been provided with this solution still do not use the product due to adverse reactions by tribes to technology. The term ideal becomes relative to location of use and culture. Engineers must obtain feedback from their potential users to identify what factors may influence a design. Only a perspective from these users will provide the necessary information they need to produce an ideal solution for that society.

Cultural considerations have major implications on how engineers approach design problems. This implies that user feedback is essential to the design process and cannot be assumed or guessed. Engineers must understand their clients to ensure they satisfy the needs of all stakeholders.

10.5 Enculturation: Becoming an Engineer

Engineering is more than simply looking, talking, and acting within a masculine culture. To become an engineer, one must traverse across the novice–expert continuum to master disciplinary knowledge, problem solving and problem identification, and understanding and engagement with data (Stevens et al. 2008). By engaging in engineering activities, engineers come to see themselves as part of a culture defined by technology because they are producers of technology and use technology to solve problems.

10.5.1 Underrepresented Groups

Becoming part of the engineering culture by developing an identity as an engineer is critical to persistence in an engineering major; this relationship is particularly strong for women (Jones, Ruff, & Peretti, Jones et al. 2012). The engineering culture may make developing an engineering identity difficult for women (Jorgenson 2002). In contrast to women, men report having an engineering identity long before beginning formal engineering training at the higher education level. They often report that they have always wanted to be an engineer, while most women do not consider engineering as a major or career until they start to apply for college. Women who do develop an early engineering identity are more likely to stay in the field (Bieri Buschor et al. 2014; Godwin et al. 2016); however, many women find engineering to be incompatible with their gender identity, which can lead to stress, questioning of ability, and poor achievement expectations and performance (Ancis and Phillips 1996; Rosenthal et al. 2011). Many women who decide to major in engineering typically have little knowledge of what engineers do because they often do not have the tinkering experience so characteristic of males; however, tinkering experiences are becoming less regular with advancements in technology. The choice of engineering, for women, is based on wanting to do something useful with their strong math and science background (Du 2006) and a desire to help people (Miller et al. 2000).

A strong math background and a desire to help people are often not enough to interest many women to study engineering. According to Ceci and Williams (2010), sex differences in rates of participation in math-intensive fields reflect career preferences, lifestyle choices, and gender inequity in engineering. This conclusion is reinforced by the data concerning the lack of sex differences in math achievement worldwide, but does not account for other barriers to engineering careers placed on women by some countries' culture. In their meta-analysis of TIMMS (Trends in International Mathematics and Science Study and the Programme for International Student Assessment) data, Else-Quest et al. (2010) concluded that girls do as well as boys in math even though they report less confidence in their mathematical abilities. The meta-analysis also found that boys were more motivated to succeed. It is hypothesized that a lack of confidence, rather than a lack of ability, is the reason why girls are less likely than boys to pursue careers in science, technology, engineering, or mathematics. Factors in the TIMSS data responsible for small differences were education, curriculum, and the value that schools, teachers, and families placed on girls learning mathematics. When male–female differences in mathematics achievement are found, they are correlated with gender inequity. The more inequity, the larger the performance gap favoring males (Guiso et al. 2008); however, a state-by-state comparison of mathematics achievement in the United States found that girls and boys do equally well on state standardized math tests from elementary through high school (Hyde et al. 2008). Girls and boys need to develop a strong engineering identity to strengthen interest and reduce the likelihood that they will transfer out of an engineering major. This is a statistically significant relationship.

Jones et al. (2012) reported a correlation of −0.43 with engineering identity and changing major for men and −0.69 for women. For both men and women, successful enculturation into the world of engineering means internalizing an engineering identity, adapting to the culture of engineering by adopting the norms and values of engineering, and establishing solidarity with others in the profession (Drybaugh 1999).

Engineering is a discipline that serves people, but has long been a profession predominantly made up of white, privileged, males (Bix 2004; Drybaugh 1999; Frehill 2004). To be an engineer one must look, talk, and act like an engineer (McIlwee and Robinson 1992). As a consequence, women engineering students often feel like outsiders who do not belong and are not part of the culture of engineering (Foor et al. 2007) prompting them to change majors (Marra et al. 2009). Minority of women in engineering feel particularly excluded as demonstrated by lower feelings of inclusion the longer African American women stay in an engineering program (Marra et al. 2009). This feeling is exacerbated if women of color are poor and lack the cultural capital of their white, female counterparts studying engineering (Foor et al. 2007).

Some aspects of the environment contribute to the masculine nature of the culture. Du (2006) found that project spaces were often strewn with beer bottles, pornography was on the walls, and male students engaged in swearing, aggressive behavior in discussion, and jokes using a technical vocabulary. In addition, male engineering students often held and transmitted negative stereotypes about women's abilities in engineering (Jones et al. 2012). Discourse patterns in whole class discussions and teams also reflect a masculine way of doing engineering (Tonso 1996).

It is a culture where hands-on work is valued and there is a fascination with tinkering and/or making; however, the farther removed engineers are from the production of technology, the less respect they receive from other engineers (Robinson and McIlwee 1991). One female student who was having a difficult time fitting in to the technical culture of engineering put it this way:

> *I did not know that there is such a high demand in the technical part. I felt so stupid because there was something they [males] knew before and I did not know. I am taking some training courses in my spare time, and I think I will reach the same level as them in one or two more semesters.* (Du 2006, p. 38)

Despite studies that document the negative effects of engineering culture on women, there are studies that find that women are not affected by stereotyping of engineering as a male domain. It is unclear whether these findings are due to a change in the culture of engineering, changes in the way engineering is taught, or changes in the culture at large (Beasley and Fischer 2012; Crisp et al. 2009; Jones et al. 2012). Initial hints suggest that good teaching may be responsible for this cultural change. One key feature of engineering programs is problem-based learning. This approach provides students with experience solving problems and working in teams. It is a strong socializer for males and provides them with a professional engineering identity. It also works for females but the impact isn't as strong (Du

2006). Another way that an engineering identity is acquired is through opportunities to work and learn in industry. Workplace experience can help individuals make the transformation from engineering students to students of engineering (Dehing et al. 2013). This is especially true when the workplace supervisor perceives the student as an engineer. Students come away from the workplace experience with a better understanding of what their professional future will be like.

A more metacognitive approach also strengthens professional identity. Creating professional portfolios helped engineering students become more aware of their own values and interests in engineering and was equally successful with males as with females. The process of putting a portfolio together helped engineering students define themselves as engineers (Elliot and Turns 2011). Metacognitive activities such as the creation of a professional portfolio strengthen group membership because metacognition is not generic, but rather reflects a specific discipline (Bransford et al. 2000). In other words, metacognition supports thinking like an engineer, and when one thinks like an engineer, one is an engineer. The impact of metacognition on professional development is not limited to engineering. It has been found to occur in fields as diverse as teacher education (Graham and Phelps 2003) and law (Fruehwald 2015).

Doctoral students are enculturated into the world of academic engineering through grantsmanship to become academic capitalists. Being a successful engineer/engineering researcher is equated with obtaining external funds. In this culture, students and faculty who receive multi-year funding are perceived as being better engineers than less successful grant writers (Szelenyi 2013).

10.6 Redefining Engineers

Data about how individuals become enculturated into the world of engineering came from studies that predominantly used surveys and questionnaires that could be analyzed statistically. These surveys looked at identity (Dehing et al. 2013; Elliot and Turns 2011), identity and stereotypes (Jones et al. 2012), or self-esteem and self-efficacy (Crisp et al. 2009; Marra et al. 2009). Other survey studies addressed attrition from the major using the National Longitudinal Study of Freshman (Beasley and Fischer 20120) or an instrument design to measure belonging in engineering (Marra et al. 2012).

Historical studies relied on document analysis of archived materials, newspaper reports, and research literature (Bix 2004; Frehill 2004). All but one of the remaining studies used some form of qualitative analysis such as large-scale ethnographies (McIlwee and Robinson 1992; Stevens et al. 2008; Tonso 1996) or an ethnography of the particular to tell one person's story (Foor et al. 2007). Drybaugh (1999) used three qualitative techniques (i.e., observations, interviews, and focus groups) to examine enculturation into engineering, while Du (2006) used comparative case studies to examine constructing an engineering identity. To look at the socialization of graduate students in engineering, Szelenyi (2013) conducted interviews. Only one study used both quantitative and qualitative data sources and analyses to examine the culture of engineering for men and women (Robinson and McIlwee 1991).

10.6.1 The Need to Broaden the Definition of Engineering and Engineering Education

From the cited research, we can see that the definition of an engineer should be broadened especially in regard to what an engineer looks like and does. This process should be started before students decide to enter a university program in engineering. The new K-12 Next Generation Science and on Engineering Standards (NGSES) are a good beginning, but we will have to expand upon them. Curricula is needed at the K-12 level that goes beyond the current NGSES focus of understanding the design process and how engineering and science are the same and different. Additions to the curricula should focus on engineering that includes opportunities to both tinker and develop an engineering identity. Engineering activities in the curricula should be contextualized in such a way as to make clear how engineering contributes to social good and how expanding who becomes an engineer is part of contributing to the social good. Early experiences of this kind would increase both women and minorities' interest in engineering majors.

Change has to also take place in university settings. Professional societies focused on women (e.g., Society of Women Engineers, Association for Women in Computing, and Women in Science and Engineering) and minorities (e.g., National Society of Black Engineers, American Indian Science and Engineering Society, and Society of Hispanic Professional Engineers) as well as successful gatherings such as the Grace Hopper Celebration of Women in Computing (http://gracehopper.org) and the Richard Tapia Celebration of Diversity (http://tapiaconference.org) are good examples that aim to gather and recruit underrepresented groups. These efforts help universities and engineering programs toward increasing diversity of their students and the engineering profession, but unintentional biases may still exist. Engineering instructors need to become aware of inclusive pedagogical practices and how some traditional practices may create what Hall and Sandler (1982) called a chilly climate for women. Hiring more female and minority engineering professors who can serve as role models can send a message that engineering is for everyone. Increasing the visibility and support of organizations such as the Society of Women Engineers (SWE), Women in Science and Engineering (WISE), National Society of Black Engineers (NSBE), and American Indian Science and Engineering Society (AISES) also indicates that diversity is valued. Professors can also provide opportunities for women and minorities to take leadership positions in team projects and ensuring that the team respects and follows them as leaders. Finally, there should be an institutional mechanism for reporting incidents, activities, and behaviors, whether initiated by professors or fellow students, that create a hostile environment, exclude women and minorities, and reinforce stereotyping of who is an engineer.

10.7 Conclusions

Changing current practices can be a daunting task, especially within institutions that have longstanding traditions and entrenched individuals who live by the notion that "if it ain't broke, don't fix it." The issue is that traditional systems don't appear broken to those who have found it to be successful for themselves. Improvements are merely an inconvenience that will cause an inordinate amount of unnecessary time to implement. It is this approach that perpetuates the misconception that engineering is boring, difficult, and only for males who are good at math and science. This misconception is held beyond the United States, as supported by *Chapter: Engineering Education in Higher Education in Europe* by Corlu et al. (2018), and expands our discussion to include the impact that history, innovation, and instructional best practices can also have on engineering education. Changing these aspects is highly influenced by the current culture established in engineering education institutions. It is important that we address these aspects to create a better-informed society interested in pursuing engineering careers. What must be undertaken is massive organizational change, both within higher education and industry. Further studies like the ethnographic study of an engineering division within a large American high-tech corporation conducted by Kunda (2009) will help inform this change. The culture of engineering education and engineering industries must provide a platform for a new generation of learners and future workers that will provide diverse perspectives to address twenty-first century grand challenges. This will require a focus on the relationship between engineering organizational culture, engineering identity, and the perception/image projected by engineering to the general public (Hatch and Schultz 1997). Additionally, *Chapter 7: Technology, Culture, and Values – Implications for Enactment of Technological Tools in Precollege Science Classrooms* by Waight and Abd-El-Khalick (2018) reminds us that technology and engineering go hand-in-hand. Technology can make life better, but the use of technology in the early years of education has the potential for negative consequences on student perceptions. Technology is taken for granted in university-level engineering education, but can negatively impact perceptions of engineering if the technology is problematic.

10.8 Recommendations for Engineering Educators, Learners, and Practitioners

This review has made several suggestions for recommended changes in engineering education and practice that can help the evolution of the engineering discipline. These recommendations include:

- Improving education and awareness of engineering within the general public. The public's perception is a key indicator of how engineering culture is viewed from outside the profession. Diversifying the field starts by increasing interest beyond those who have already been enculturated.

- Increasing educational environments that engage students in deep thinking through active learning approaches. Modifying engineering education to be more hands-on and less teacher centered will provide positive experiences to retain students.
- Making the student–teacher relationship more personal to provide students with opportunities to become more deeply acculturated in the field. These opportunities could include teaching and research experiences.
- Greater support by administrators for the scholarship of teaching engineering. A greater emphasis on teaching will allow faculty to expend more effort in turn providing better experiences for students.
- Increased opportunities for engineering students and engineers to know their customers. Designing a product should be for the sole purpose of solving a client's need. Knowing your client is essential in ensuring the solution is appropriate.
- Diversifying engineering and broadening the definition of what an engineer looks like and does. The notion of engineering being strictly for white males good at the hard sciences is a misconception that has been perpetuated and needs to be dispelled.

Enacting these recommendations should prove to positively impact the perceived and existing culture of engineering.

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