1-1-2021

Who Engineering Includes Impacts How Engineers Work: Diversity Challenges and Design Thinking Solutions

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Recommended Citation

Secules, Stephen; Coso Strong, Alexandra; Fletcher, Trina. "Who Engineering Includes Impacts How Engineers Work: Diversity Challenges and Design Thinking Solutions." Implementation Strategies for Improving Diversity in Organizations, edited by Claretha Hughes, IGI Global, 2021, pp. 224-248. http://doi:10.4018/978-1-7998-4745-8.ch008

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1. Introduction

Although many view engineering as a purely technical domain, it is fundamentally social, as it is always working with and in service of people (Bucciarelli, 1988; Hynes & Swenson, 2013). Every stakeholder connected to a project is a person: the client and organization, the design team, other consultants, impacted members of the public, government regulators, shareholders or other investors, and representatives of other concerns such as the environment. In an increasingly global and interconnected society, the people with whom and for whom engineers must work have become increasingly more diverse and interconnected. To be an engineer is increasingly to communicate with, empathize with, and design for the problems of a wide variety of individuals spanning increasingly diverse demographics and perspectives.

Engineers have largely not increased their diversity parallel to the wider diversity of their stakeholders. Engineering has historically and persistently been a field that is dominated by certain demographic groups (Secules, 2017b). Since its formal organization in the 19th century, engineering has been predominantly white, male, straight, middle-class, and western-centric. This exclusion was formalized through educational pathways and professional societies through the 20th century. In the late 20th century, Civil Rights and Women's Rights movements paved the way for the moral imperative and progress for diversity in professions like engineering. Nevertheless in the 21st century, trends for demographic shifts in engineering have stalled in the United States.

This exclusion of other groups from engineering has meant that engineering solutions are often designed with a bias towards the same exclusive demographics as the engineers themselves. As progress on diversity stalls and the challenges engineers must respond to increase, we see and advocate a set of solutions grounded in design thinking (Brown, 2009) that 1) changes **who** engineers are by designing diversity into the profession, and 2) changes **how** engineers work within their existing and future professional settings (Figure 1).

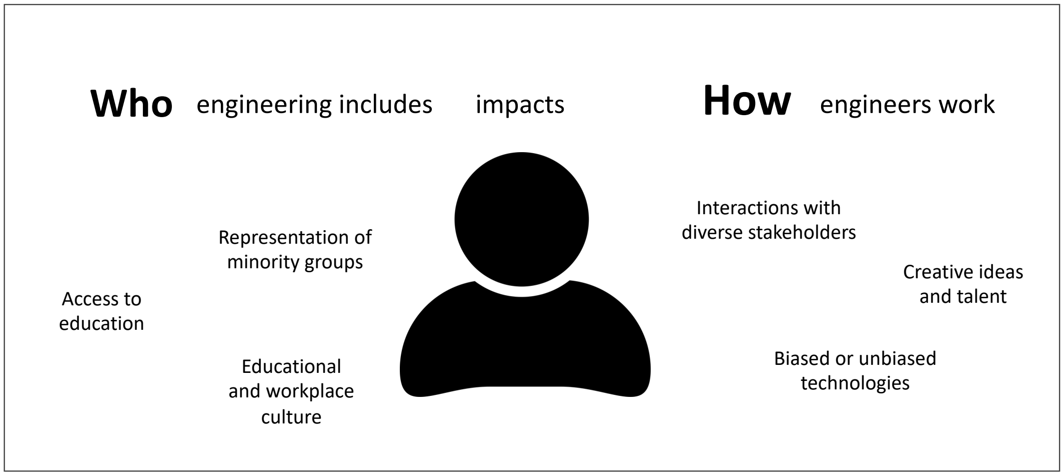

Figure 1: Changing Who Engineering Includes Will Impact How Engineers Work

1.1 Authors' Perspectives

The authors of this chapter come from an engineering education research perspective. Each of us have experience with educational and professional engineering contexts, and our perspective is informed by the knowledge that these are interconnected systems. In our current roles as engineering educators and researchers, we are cognizant of the ways that education is creating or reinventing the engineering profession of tomorrow, and the ways that our educational system can be bound up in the current and eventual realities of the engineering profession. By focusing our attention on the lack of diversity and opportunities for change in the engineering profession, we hope to encourage further collaboration and cross-pollination of ideas about diversity challenges from educational contexts to industry work settings and vice versa.

2. Issues, Controversies, Problems

2.1 The Engineering Profession Lacks Diversity

2.1.1 History of the engineering profession as exclusive

When discussing diversity in engineering, historical context helps clarify the particular aspects of exclusion at play that may not be present in other professions (Secules, 2017b). Although the field of inventing and using math and science to solve problems existed informally for several hundred years, the engineering profession was largely formalized in the 19th century (Oldenziel, 1999). Prior to the 19th century, the inventive field (represented in western society by terms like "the useful arts") was largely inclusive. Although women were socially constrained to the domestic sphere, their inventions were recognized as similar to men's in the industrial sphere. Likewise, labor classes constructing a building were seen as part of the engineering work.

The formal organization of the engineering discipline in the 19th century created a professional class for engineers that was exclusive to middle-class white men (Oldenziel, 1999; Secules, 2019). To become an engineer required higher education training that was exclusive to this group. Publicly-funded Historically Black Colleges and Universities were excluded from engineering and science degrees through much of the 20th century and only won access due to legal challenges, some of which still continue today (Fletcher et al., 2019; Slaton, 2010b). In white universities where engineering was offered, a common gender divide separated men as engineers and women as home economics majors (Bix, 2002).[1] Although the sudden need for technological advancement in World War II opened employment possibilities for women and racial minorities, these employment options were temporary and limited as the educational system and professional societies prevented full access to the profession (Bix, 2004; Shetterly, 2016; Slaton, 2010a). Subject to persistent structural exclusion, a stereotype of a straight, White, male middle-class professional came to be synonymous with engineer, creating a system of cultural embodied exclusion (Faulkner, 2007a; Secules, 2019). In the late 20th century, Civil Rights and Women's Rights movements paved the way for the moral imperative and progress for diversity in professions like engineering and created diversity initiatives for workplaces and education. In the next section we take stock of the current state of engineering diversification in the 21st century.

2.1.2 Current State of Engineering Diversification

The current state of diversity in engineering is best reflected by noting diversity at stages of academic and career progression (Figure 2). At the pre-college level (i.e., K-12 schooling and informal learning), racially underrepresented minority (URM) students are just as likely as their majority counterparts to be interested in pursuing Science, Technology, Engineering or Mathematics (STEM) education and careers. However, they are less likely to actually apply, enroll, and complete STEM degrees than their White peers (Gasman & Nguyen, 2016). From a gender standpoint, prior to college enrollment, research shows that female students perform equal to or better than male students in math and science classes, yet in most STEM fields their participation is much lower than their male identifying counterparts (O'Dea et al., 2018). According to the National Center for Educational Statistics (NCES), women comprised only 36% of all STEM degrees awarded in 2017 and only 22% for engineering (U.S. Department of Education, 2017).

[1] The rare female engineer was sometimes called an "Engineeress" (Bix, 2004).

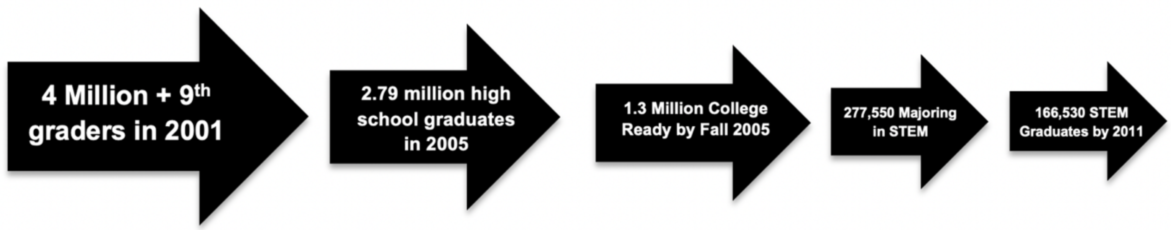

Figure 2: The Leaky Pipeline in Engineering and How African American Students are Impacted
(adapted from President's Council of Advisors on Science and Technology, 2012; Reid, 2014)

Finally, the engineering profession in the United States is overwhelmingly White non-Hispanic (70%) or Asian (16%) and compromised of men (85%) (National Academy of Engineering, 2018). All other racial / ethnic groups and women are underrepresented in engineering relative to their national demographics. For example, women make up 51% of the US population (United States Census Bureau, 2019) but only 15% of the engineering workforce (National Academy of Engineering, 2018). African Americans make up 13% of the US population (United States Census Bureau, 2019) but only 4% of the engineering workforce (National Academy of Engineering, 2018). Thus although some progress is being made at in pre-college and higher education spaces, the engineering profession continues to be even less diverse than the stages of educational attainment that feed into it. Table 3 below further highlights the lack of parity across varying racial / ethnic groups and gender when considering all engineering and science occupations.

S&E Occupations	Race/Gender Population	U.S. Population
49%	White men	31%
18%	White women	31%
14%	Asian men	3%
7%	Asian women	3%
3%	Black men	6%
2%	Black women	7%
4%	Hispanic men	9%
2%	Hispanic women	8%
2%	Other men and women	3%

Table 3: Workers in science and engineering occupations across gender and racial/ethnic groups
(adapted from National Center for Science and Engineering Statistics, 2017)

While the underrepresentation of other minority groups is harder to assess, several scholars have identified issues with representation and inclusion of LGBTQ engineers (Cech & Pham, 2017; Cech & Waidzunas, 2011), low socioeconomic status and first generation college attendees (Smith & Lucena, 2016), disabled students (Groen et al., 2018), and other groups.

Further, people at the intersections of multiple systems of inequality / oppression, for example Latina women from low socioeconomic backgrounds, face even greater challenges and are even harder for researchers to assess (Camacho & Lord, 2011; Mitchell et al., 2014; Secules, Sochacka, et al., 2018). In general, the engineering profession has remained stagnant when it comes to diversifying the field for individuals from varying backgrounds.

2.2 How Circumstances Prior to the Profession Create the Lack of Diversity

2.2.1 Pre-college Access to Engineering Education for Diverse Populations

While the reasons for the lack of diversity in engineering are many, there are a few well-documented areas we continue to witness related to diverse populations in engineering at the higher education level and in industry. They include (1) inadequate academic preparation for engineering courses prior to entering college, (2) a lack of access to high quality activities and programming to increase interest in pre-college engineering education and (3) a lack of access to mentors and role models within engineering who they can seem themselves in.

When considering academic preparation for college-level prerequisite courses for engineering and upper-level engineering courses, studies have shown that heavily URM populated secondary institutions and high schools in low-socioeconomic status neighborhoods often do not have adequate facilities, labs or qualified teachers for courses students need to enter engineering in college (Change the Equation, 2015; James & Singer, 2017; Smith-Evans et al., 2014). Additionally, research has found that URMs, especially girls of color, are often steered away from math and science classes across all schools and encouraged to take classes that promote and focus more on communication and dialogue, which leads to the underrepresentation of URMs in Advanced Placement (AP) STEM courses and those same students scoring lower on ACT and SAT exams (Smith-Evans et al., 2014). In many of the same neighborhoods and schools, students are less likely to have programs or course electives, in school and out-of-school, which allow them to learn more about engineering education including more known national programs such as FIRST Robotics and Project Lead the Way (PLTW).

Research has shown that a lack of mentors and role models within pre-college educational settings, both formal and informal, have played a role in the stagnant and, in some cases, declining number of URMs pursuing engineering, especially women within that population (Fletcher et al., 2017; James & Singer, 2017; Mondisa, 2015). Mentors and role models play a major role in whether or not underrepresented students believe that they can succeed in STEM professions.

2.2.2 Diversity, Equity and Inclusion and Engineering Education in Higher Education

The previous section focusing on challenges within the pre-college space highlights the eventual underrepresentation we see at the higher education level. According to the National Center for Educational Statistics, as of 2017, women only made up 25% of engineering bachelor's degrees awarded, although they made up 57% of all bachelor's degrees awarded that year (U.S. Department of Education, 2017). Although this number clearly reflects parity issues within the field, it should be noted that that figure is up from 20% in 2015. Additionally, there have been incremental improvements in the number of women within the varying ethnic groups over the years. For example, the percentage of White women obtaining engineering degrees among all White students increased from 18% in 2012 to 21% in 2017. For African American women, their share of their ethnic group increased from 24% to 27%. Similar results were found for Hispanic/Latinx women with their share increasing from 21% to 24% between the same timeframe (U.S. Department of Education, 2017).

Beyond representation, there are also interconnected issues of inclusion in higher education. Students in visibly minoritized populations in engineering, such as women and Black and Latinx students, are often subject to spotlighting by faculty and peers (McLoughlin, 2005) and a feeling of hypervisibility (Blosser, 2019), due to their lack of critical numbers in engineering classes. This experience of hypervisibility can create a sense that each individual is representing their entire population group. The result can be circumstances that introduce and reinforce stereotype threat, which has been shown to decrease students' academic performance (Bell et al., 2003). In addition, majority peers and instructors often form classroom culture and practices around majority cultural norms, and construct narratives about individuals who do not fit into those norms as an individual deficit (Secules, Gupta, et al., 2018). In sum, the many individual mental and interpersonal strains created for minoritized students result in an inequitable educational experience.

The experience for less visible minorities, such as LGBTQ students and first generation college students, in engineering higher education is also difficult. LGBTQ students experience marginalization and feel pressure to pass and hide their LGBTQ identities to fit in with the mainstream (Cech & Waidzunas, 2011). Students who are first generation college students must draw on alternative forms of cultural capital in a system that is less familiar to them (Smith & Lucena, 2016). In addition, as experiences that are relatively hidden from caring instructors and without institutional support structures, these students are often left with less support than other minoritized student groups (Secules, Sochacka, et al., 2018). Similarly, students at the intersection of multiple systems of oppression may experience additional challenges not only with multiple forms of marginalization, but also with university support structures, for example being one of a few Black women or lesbians in a women in engineering support group (Secules, Sochacka, et al., 2018).

2.2.3 Impact of Pre-college and Higher Education Issues on Diversity in Engineering Industry

Ultimately, the net effect of exclusion and inequity in pre-college and higher educational settings compounds in engineering industry. As noted, there is an even greater lack of diversity in the engineering profession, as some diverse individuals who completed engineering degrees will choose to leave the field after completing their degrees. Hiring practices can exacerbate these circumstances, with workplaces choosing individuals who "fit" more easily with a company culture (Rivera, 2012). Given the racial, gender, class, and cultural makeup of engineering workplaces, these forces function as discrimination, whether intentional or unintentional. This process of recreating demographic associations with engineering through cultural processes accords with a theory of cultural reproduction (Secules, 2019; Seron et al., 2015), wherein the culture created by a dominant demographic group creates an unwelcoming environment for non-dominant groups and thereby recreates their own demographic dominance. The process of creating masculine demographic associations has been widely confirmed across several examples of masculine-associated professions and hobbies (Bird, 1996; in engineering, Faulkner, 2007b), and the same likely holds true for other demographic groups.

As a specific example, women of color in engineering experience challenges based on lack of role models (Ross, 2016), thus there is an additional compounding effect from the lack of inclusion of women of color, a specific enacted example where lack of inclusion recreates demographic exclusion. In addition, women of color in engineering note gender and racial bias, stereotypes experienced in the workplace, unfair performance evaluations, and lack of honest feedback (Fletcher et al., 2017; Ross, 2016; Yates & Rincon, 2018). One in four women leave the engineering profession within the first five years, a rate much higher than their male counterparts (Yates & Rincon, 2018).

2.3 How Lack of Diversity Causes Problems within Engineering Professional Work

When examining the impact of the lack of diversity in the engineering workplace, it is critical to consider the impact on the actual work of engineers. For instance, in the design of many systems, engineers can fall victim to the practice of assuming that a product design is fine "as long as it works for them and their experience" (Coso & Pritchett, 2015, p. 6). Studies of engineering organizations have illustrated how some engineers assume that they understand the experiences of everyone based only on their own experience (Coso & Pritchett, 2015). The tendency to discount or to not have awareness of the experiences of broader and more diverse user groups is compounded by the lack of diversity within engineering organizations. Engineering teams and organizations, especially those without diverse compositions, become hubs for user perspectives that are limited in their understandings of the broader population.

Homogenous engineering teams can also foster negative attitudes towards individuals from other disciplines who bring different perspectives and ideas (Coso & Pritchett, 2015). These attitudes can impact the decisions made within a product design process and ultimately, the effectiveness of the final product. Within the aerospace industry, for example, an engineering team may not only consist of engineers, but also individuals trained in human factors or psychology. Their role on the team is to identify and integrate the considerations of a diverse set of stakeholders within an aerospace vehicle design. However, when their perceptions are not valued on a team (Coso & Pritchett, 2015; Feigh & Chua, 2011) or their perceptions are not considered due to lack of representation on that team, there can be problems even later in the design process or with the final product. In the case of one aerospace organization, a human factors specialist described

> "[human factors]-related research and groups are the first to have funding cut when it comes to the budget...yet...there may be problems two years later in manufacturing that could have been prevented if the [human factors] specialists had been involved at the beginning of the process" (Coso & Pritchett, 2015).

The lack of consideration of diverse stakeholders, whether caused by an n=1 approach to design or the lack of inclusion of human factors and related professionals, can have substantial impacts on the final design of a system and/or product. In some cases, these actions can have unforeseen consequences on individual users. For instance, military aircraft and other vehicles have been traditionally built with the 90-95th percentile male measurements and body characteristics in mind (Weber, 1997). Thus, both women and small-statured men can be placed at a significant disadvantage when piloting those systems (Weber, 1997). The outcomes of this bias in engineering technologies are a result of the lack of diversity in engineering coupled with a lack of strategies to think and design across different populations. In recent years, noted examples of bias have been found in facial recognition software, where products work best for white faces (Garvie & Frankle, 2016). In 2018 a video of a Black person attempting to use a soap dispenser went viral—the soap dispenser worked only for lighter and more reflective materials. Finally, for a period of time, car crash test dummies were designed for an average adult male-sized person, and thus the safety conditions of cars were not tested or designed for the average sizes of women or children (Criado-Perez, 2019). By excluding particular groups in the engineering decision-making process, engineers are creating exclusionary products and systems that have broad societal consequences that are serious and urgent.

3. Solutions and Recommendations

3.1 Two Cases for Diversity in Engineering

There are typically two parallel arguments for working to diversify the engineering profession: 1) a pragmatic business case and 2) a social justice case (Tomlinson & Schwabenland, 2010). We name both here because it is important to understand the guiding motivations of yourself and of others who take up this cause.

In the pragmatic / business case, there is a profit-oriented argument for diversifying the engineering profession (Kochan et al., 2003). The typical elements of the pragmatic case are: meritocracy (if we anticipate that merit is evenly distributed across populations, then the best and brightest engineers will come from a cross-section of demographics), creativity (people from different backgrounds think differently and the widest variety of ideas will come from the widest group), public relations (valuing diversity is a positive public relations move in today's society), and ultimately profit (diversity will lead to better work and therefore profit). Many workplaces are oriented primarily by these pragmatic elements of diversity and inclusion (Ahmed, 2012; Tomlinson & Schwabenland, 2010). By understanding that context when beginning to frame and enact solutions, individuals can consider how a business-oriented audience is likely to receive their messaging and what reforms will be considered a priority.

In the social justice case, there is a moral imperative for diversifying the engineering profession (Secules, 2017b; Slaton, 2015). The typical elements of the social justice case are: history (correcting a professional legacy of exclusion), privilege (redistributing the social power of the engineering profession), democracy (creating greater access to the tools of engineering), and ultimately justice (seeking a more equal world). This chapter opened with a historically-situated social justice framing for diversity in engineering, and this is often what orients academics, activists, and critical scholars who work towards diversification. For individuals coming from this perspective, there is typically a moral imperative and an urgency to correcting historical and present-day inequality that can be at odds with proponents of the business case.

Both the pragmatic case and the social justice case for diversity have communicative value-- commonly one or the other framing is more accessible to a particular audience. Yet both of these cases have some drawbacks. The pragmatic case could be considered optimistic and unrealistic about many lived realities of diversity in workplaces. Diversity may have a net social good, but it does not always linearly increase merit, productivity, good will, and a financial bottom line (Leonard et al., 2004). Sometimes increasing diversity causes workplace tensions, tough decisions, and accusations of special treatment. The pragmatic business case can lead to either lip service or naive faith regarding diversity that does not take into account reality (Ahmed, 2012; Thomas, 2018). The social justice case takes on resistant constituents and calls out problems, but may be heard as a critique only and may not take into account the parallel goals and interests of a non-activist, for-profit business. Social justice cases for diversity, while prominent in academia and activism, can be sidelined in professional settings (Ahmed, 2012; Thomas, 2018).

This chapter proposes a third approach to diversity in engineering, one that draws on skills incumbent within engineering work. We propose that engineering is specifically connected to diversity through design. As engineering design helps create the built environment and technology, it has major impact on power, privilege, and justice. As engineering is pursued by individuals, their design is impacted by their individuality and thus their diversity. Engineers, and other professionals, can take a solution-oriented *design thinking* approach to diversifying engineering.

3.2 Design Thinking Approach to Diversity

Design Thinking has become a popularized term for describing the activities that an individual may employ to understand a problem and potential user population, generate ideas, prototype and test, and engage in an overall iterative process (Brown, 2009; Brown & Katz, 2011). Moving beyond the term, design and design approaches to problems have been long considered a central activity of engineering (Dym et al., 2005). Engineers are introduced to design activities as early as their K-12 education (Crismond & Adams, 2012) and in the first year of many undergraduate engineering programs (Froyd et al., 2012).

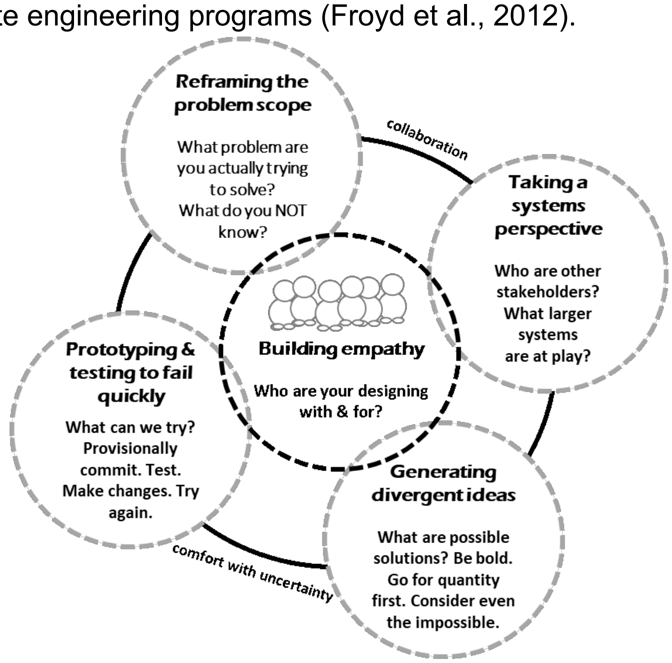

Figure 3: Components of Design Thinking

Figure 3 presents some of the key components of the design thinking process, and Figure 4 presents an application of design thinking to aspects of professional diversification. When engaging in Design Thinking, engineers question a problem to understand what a client or customer really want and whether the problem is even the root problem. Before considering a single solution, engineers seek to be divergent in their thinking, generating many possible (and even some seemingly impossible) solutions. Much of these initial design activities are performed with large amounts of uncertainty, such as with incomplete information or ambiguous objectives from the client. The challenges we face to support the diversification of the engineering profession and to enable solutions that consider more diverse user populations are large, complex, and filled with uncertainty. This uncertainty and complexity are at the heart of Design Thinking and are aligned with the skills engineers already use.

Another critical piece of this design approach is prototyping and experimentation. Prototyping is, in itself, a learning process. Engineers develop early state prototypes with the intention of them failing quickly, in other words, enabling them to explore many ideas in a short period of time (even if they fail), rather than spending a significant amount of time on a single idea, especially early on in the process. Prototyping new solutions for recruitment and/or workforce development, for example, would allow HR professionals and practicing engineers to learn more about the problem and the individual groups they are looking to hire. Overall, these design skills (i.e., problem definition, empathy, comfort with uncertainty, collaboration, idea generation, prototyping) have become important components of the engineering profession and engineering education, and many of these skills could be leveraged to improve diversity within engineering practice. The subsequent sections present different approaches for leveraging design skills to improve diversity during pre-college/higher education in engineering, within engineering workplaces, and within engineering professional work.

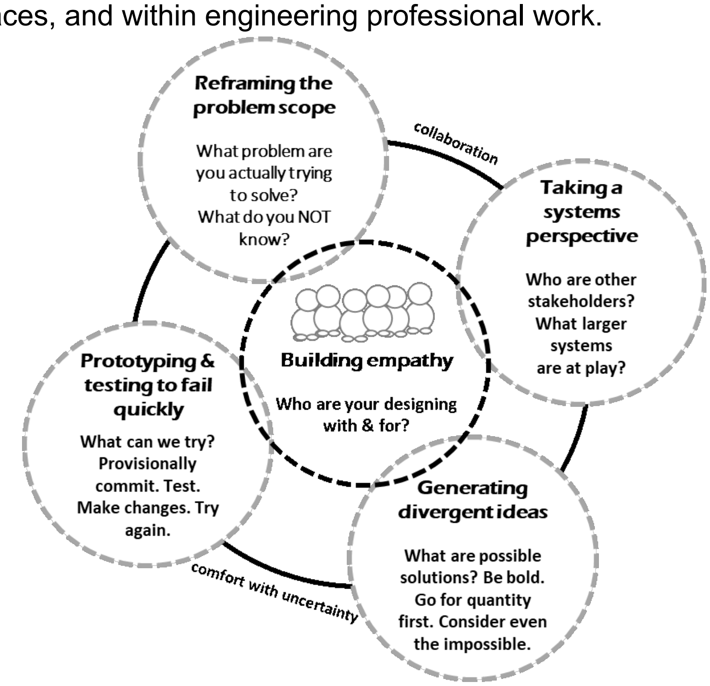

Figure 4: Design Thinking focused on Diversity, Equity, and Inclusion

3.2.1 Solution #1: Increased Collaborations between Educational Institutions and Industry

Pre-college, higher education institutions and industry should make a concerted effort to better understand the roadblocks and barriers linked to underrepresented students and their quests for access to engineering education. These challenges that essentially creep into the higher education system, should also be kept in mind as the impact then affects the progress industry hopes to have from a diversity and inclusion standpoint within their organizations. When considering the desire to increase equitable access to jobs and inclusion for diverse employees in industry positions, improving collaborations between educational institutions, pre-college and college, and industry is of great importance.

There are several avenues that can help make successful collaborations. First, prioritizing access to high quality engineering education for URMs will provide a level of exposure to the fields that would increase students' chances of being interested in engineering. Industry partners should be involved and engaged so that students can have real-world examples of their careers post higher education. Secondly, collaborators must champion equitable access to and support within engineering education programs for both pre-college and higher education programs. By making entering and remaining in engineering education more equitable, the number of URMs pursuing engineering as an undergraduate student should increase and the number of students who leave undergraduate engineering programs should decrease. Third, training on diversity, equity and inclusion for institutional leadership, faculty and staff at all educational levels should be implemented and fully supported by institutional leadership. This training could be aligned with existing efforts to develop industrial leaders' diversity intelligence, which enables them to value differences in individuals, without seeking to make the same (Hughes, 2016, 2018). Lastly, there should be a concerted effort to spread knowledge on the need and benefits of diverse populations in engineering within the K-12 space, higher education and within industry. Companies that are working with educational institutions should increase their efforts to support student success within engineering not only while the students are in school but also as they transition into industry and throughout their careers.

In general, these groups could work more purposely towards 1) understanding and building empathy for diverse populations and the value they add to organizations, 2) collaborating together to generate ideas about how to take overall diversity, equity and inclusion efforts to higher levels, and, lastly, 3) experimenting and prototyping ideas in all the spaces (i.e., K-12, higher education, industry).

3.2.2 Solution #2: Collectively Reflecting on Diversity and Inclusion

Engineering professionals can turn to their own organizations and reflect on their current diversity. Diversity and inclusion has been discussed as a "wicked problem" (Zoltowski et al., 2017), or as a complex interrelated problem that is well-poised to be better understood by a design thinking framework. Thinking creatively and iteratively about such a seemingly intractable problem can give people a better appreciation of the realities and constraints, new solution areas, and better regrouping after initial failures. Workplaces can also be conceived of as complex systems with many stakeholders. By thinking of each of these stakeholders as holding useful local knowledge about diversity and inclusion, and uncovering and mapping these perspectives in a safe environment, workshop leaders outside of a workplace have helped trigger reflection, action, and coordination around diversity and inclusion.

In a series of interactive workshops with academic and industry professionals, Secules and his collaborators have run an activity that helps people think about the local knowledge of challenges and strategies for improving diversity and inclusion in aspects of the organization (Secules et al., 2019). After discussing organizational mission and thinking about overlapping issues of diversity and inclusion, the workshop organizers provide a framework for thinking about aspects of a professional organization. For instance, when presenting at Carnegie Institute for Science, the categories co-developed with employees were: Policy, Personnel, Fundraising, Communication, Research & Development, and Outreach. All employees were then asked to create Post-it Note responses with categories of diversity and inclusion 1) questions, 2) known challenges, and 3) possible solutions that fit within each of the categories. They then posted them on large pieces of paper throughout the room, read each other's responses, and built on those responses (e.g., asking and answering each other's questions). The approach typically triggers reflection, conversation, and concerted action related to diversity and inclusion that has otherwise not been thought about or has stagnated. A similar approach was taken in a workshop with Penn State University, specifically around staff and faculty inclusion for LGBTQ and disabled students. The approach draws on Design Thinking approaches to problem scoping and ideation with a large group of stakeholders who have localized knowledge of an issue.

3.2.3 Solution #3: Designing for Diversity within Engineering Practices

Even with increased diversity within the profession, engineering will continue to be impacted by the lack of diversity that exists at the micro-level, particularly within engineering teams. It is practically not possible to represent all intersections of human experience on a single team. Thus, organizations and engineers should consider implementing engineering design strategies focused on human-centered and community-oriented design practice to help engineers engage in and elevate the diverse perspectives of clients or customers. This solution may be implemented in the form of workforce development or become translated into interview questions to search for engineers with a mindset towards these design practices.

Design for extremes. Grounded in universal design principles (Mcadams & Kostovich, 2011), many organizations design their products with the "extreme" users in mind (e.g., those who are at the extremes physically, those who hold viewpoints at the extremes). For example, one of the most prominent companies for kitchen tools, OXO, was inspired by the experience of a family member with arthritis who was trying to use a vegetable peeler (Wilson, 2018). By considering individuals who face challenges engaging with certain types of handles alongside those who don't, the design team at OXO created an innovative, intuitive, and comfortable handle for what became the Good Grips line that could be used by all (Wilson, 2018). The principles behind universal design enable the development of more accessible designs without the stigma that can be created around designing for a particular 'extreme' of the population. As a result, engineers could leverage this strategy to consider the experiences of those who are not represented within their engineering teams. First, what perspectives and experiences would someone from this sub-group hold? What physical or other characteristics might impact the ultimate design?

Collaborate across disciplines. In the same manner that engineers are trained in design, those individuals with a background in human factors, psychology, and/or cognitive engineering are trained to identify and integrate the considerations of a diverse set of stakeholders within a design. Currently some organizations are embedding these individuals within design teams to help those teams consider project stakeholders early and often (Coso & Pritchett, 2015; Pritchett & Strong, 2016). Alternatively, organizations can create opportunities for these specialists to consult on various projects (Coso & Pritchett, 2015; Pritchett & Strong, 2016). For example, a human factors specialist can be consulted to develop and test prototypes with an array of user abilities, constraints, and values. Therefore, even though the engineering team may not be diverse or have the training to incorporate these user considerations, the team has leveraged the expertise in their company to develop a product that can be used by a diverse population. While there are still challenges with this approach, as described in Section 2.3, HR professionals and engineers can promote this collaborative behavior by increasing the awareness of and appreciation for those with human factors or related specialties among existing employees and new employees.

4. Future Research Directions

There are several prominent research directions for broadening diversity and inclusion in the engineering profession. As noted, the authors of this chapter are members of the engineering education research community. At each stage of the educational and professionalization process, there are untold stories and unexamined issues in problematic cultures that recreate histories of demographic exclusion in the engineering profession. Taking on qualitative, critical, interpretive, or anthropological lenses to look at these cultural processes can help uncover new ways to shift that persistent pattern (Secules, 2017a).

In particular, we call for further collaborations with industry that can foster innovative research approaches. Currently, a group of engineering practitioners and engineering education scholars are working to create a scholarly community at this intersection through the development of an engineering practice research agenda (Brunhaver et al., 2018, 2019). While previous research has explored a series of topics at the intersection of engineering practice and the preparation of future engineers (e.g., experiences of those transitioning into the workforce (Brunhaver et al., 2011), the experiences of underrepresented groups in industry (Cech & Pham, 2017; Ross, 2016)), the resulting research agenda highlights a need to focus on diversity, equity, and inclusion in engineering practice.

Specifically, research should support our understanding of the power dynamics that influence who gets to participate in engineering practice, along with a deeper understanding of the impact lack of diversity has on engineering work and the workplace (Brunhaver et al., 2019). When we, as individuals, experience the societal implications of lack of diversity in engineering, the problem has already gone too far. As researchers, we need to identify the features of an engineering team, engineering design process, and an engineering organization that can prevent these situations from occurring in the first place. In addition, many organizations already work with universities and K-12 schools through outreach, scholarship, and internship opportunities. Yet, questions remain regarding what of these efforts are working, to what extent are they working, and what aspects of their design are influencing their success. Research is needed to explore existing relationships and partnerships between educational institutions and industry to examine the impacts of these partnerships and develop recommendations for achieving the greatest impact on students' pathways into and within engineering.

We note that one of the reasons more interdisciplinary workforce and education research collaboration has not yet taken place is that there are challenges faced by researchers who take on those projects. For example, access to potential research sites can be a challenge for academic researchers focused on industry settings (Stevens & Vinson, 2014). Industry also has more of an incentive for non-disclosure agreements and a desire for control over what is published about the company (Stevens & Vinson, 2014). Thus, we hope this chapter serves as an opportunity to be clear about the challenges and the opportunities that can come with taking on new cross-cutting research approaches, and an invitation for others to help overcome the challenges together.

5. Conclusion

We engaged with diversity in the engineering profession around two central topics 1) **who** engineers are in their demographic makeup, and 2) **how** that impacts engineering professional work. People engage with each of these topics from different perspectives. There are clear arguments for caring about who has access to engineering from a social justice perspective, righting historical inequities. There are also pragmatic reasons for caring about diversity in engineering, since a lack of diversity is directly tied to problems in engineering work, including biased technology and loss of talent. While we each bring our own motivations, we draw strength in fostering collective and interdisciplinary solutions that bring about multiple goals. We propose that the set of solution strategies and the framing of diversity challenges as design problems offer a new language for communication across disparate motivations and a pragmatic yet realistic framework for reasoning about these complex social issues.

6. Key Terms and Definitions

1. Design thinking: a set of activities that an individual may employ to understand a problem and potential user population, generate ideas, prototype and test, and engage in an overall iterative process.
2. Problem definition: a component of design thinking focused on formulating the scope and boundaries of an engineering design problem.
3. Idea generation: a component of design thinking focused on generating possible solutions to a given engineering design problem.
4. Prototyping: implementing and testing out ideas in an iterative way.

5. Human factors: components of engineering design that focus on the aspects related to human users and operators.
6. Social justice case for diversity: a case for the importance of diversity that is grounded in the historical inequities and exclusions associated with a given profession or national environment.
7. Business case for diversity: a case for the importance of diversity that is grounded in profit-oriented rationales based on creativity, meritocracy, and diversity of ideas.
8. Underrepresented Racial Minority (URM): a racial/ethnic group that is under-represented in the engineering profession relative to their representation in the US national population, e.g., African American and Latinxs.
9. Intersections of oppression: the co-existence of systems of power and oppression, such as gender, race/ethnicity, sexual orientation, ability/disability, and socioeconomic status.
10. Bias in engineering technologies: engineering technologies that create inequity between different groups in society, either intentionally or unintentionally.

References:

Ahmed, S. (2012). *On Being Included*. Duke University Press.
Bell, A. E., Spencer, S. J., Iserman, E., & Logel, C. E. R. (2003). Stereotype threat and women's performance in engineering. *Journal of Engineering Education*, *92*(4). https://doi.org/10.1002/j.2168-9830.2003.tb00774.x
Bird, S. R. (1996). Welcome to the Men's Club: Homosociality and the Maintenance of Hegemonic Masculinity Stable. *Gender & Society*, *10*(2), 120–132. https://doi.org/10.1177/089124396010002002
Bix, A. S. (2000). "Engineeresses" Invade Campus: Four decades of debate over technical coeducation. *IEEE, Technology and Society Magazine*, *19*(1), 20–26.
Bix, A. S. (2002). Equipped for Life: Gendered Technical Training and Consumerism in Home Economics, 1920-1980. *Technology and Culture*, *43*(4), 728–754. https://doi.org/10.1353/tech.2002.0152
Bix, A. S. (2004). From "Engineeresses" to "Girl Engineers" to "Good Engineers": A History of Women's U.S. Engineering Education. *NWSA Journal*, *16*(1), 27–49. https://doi.org/10.1353/nwsa.2004.0028
Blosser, E. (2019). An examination of Black women's experiences in undergraduate engineering on a primarily white campus: Considering institutional strategies for change. *Journal of Engineering Education*, *March 2018*, 52–71. https://doi.org/10.1002/jee.20304
Brown, T. (2009). *Change By Design*. Harper Collins.
Brown, T., & Katz, B. (2011). Change by Design. *J Prod Innov Manag*, *28*, 381–383.
Brunhaver, S. R., Jesiek, B. K., Coso Strong, A., Korte, R. F., & Stevens, R. (2018). Research on Engineering Practice : Catalyzing a Scholarly Community. *2018 IEEE Frontiers in Education Conference (FIE)*, 1–4.
Brunhaver, S. R., Jesiek, B. K., Korte, R. F., & Coso Strong, A. (2019). Research on Engineering Practice: Catalyizing a Scholarly Community, a Poster. *National Science Foundation Awardees Conference*.
Brunhaver, S. R., Korte, R. F., Barley, S. R., & Sheppard, S. D. (2011). Bridging the Gaps Between Engineering Education and Practice. In R. Freeman & H. Salzman (Eds.), *U.S. Engineering in a Global Economy.* (pp. 129–166). National Bureau of Economic Research and the University of Chicago Press.
Bucciarelli, L. L. (1988). *An ethnographic perspective on engineering design*. *9*(3).

Camacho, M., & Lord, S. M. (2011). Quebrando Fronteras: Trends Among Latino and Latina Undergraduate Engineers. *Journal of Hispanic Higher Education*, *10*(2), 134–146. https://doi.org/10.1177/1538192711402354

Cech, E. A., & Pham, M. (2017). Queer in STEM Organizations : Workplace Disadvantages for LGBT Employees in STEM Related Federal Agencies. *Social Sciences*, *6*(12), 1–22. https://doi.org/10.3390/socsci6010012

Cech, E. A., & Waidzunas, T. J. (2011). Navigating the heteronormativity of engineering: the experiences of lesbian, gay, and bisexual students. *Engineering Studies*, *3*(1), 1–24. https://doi.org/10.1080/19378629.2010.545065

Change the Equation. (2015). *Solving the Diversity Dilemma: Changing the Face of the STEM Workforce*. https://doi.org/10.1038/nbt0996-1055a

Coso, A. E., & Pritchett, A. R. (2015). Role of design teams in the integration of stakeholder considerations. *Journal of Aircraft*, *52*(4), 1136–1145. https://doi.org/10.2514/1.C032796

Criado-Perez, C. (2019). The deadly truth about a world built for men – from stab vests to car crashes. *The Guardian*. https://www.theguardian.com/lifeandstyle/2019/feb/23/truth-world-built-for-men-car-crashes?CMP=share_btn_link

Crismond, D. P., & Adams, R. S. (2012). The Informed Design Teaching and Learning Matrix. *Journal of Engineering Education*, *101*(4), 738–797. https://doi.org/10.1002/j.2168-9830.2012.tb01127.x

Dym, C., Agogino, A., & Eris, O. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, *January*. http://onlinelibrary.wiley.com/doi/10.1002/j.2168-9830.2005.tb00832.x/abstract

Faulkner, W. (2007a). “Nuts and Bolts and People”: Gender-troubled engineering identities. *Social Studies of Science*, *37*(3), 331–356. https://doi.org/10.1177/0306312706072175

Faulkner, W. (2007b). “Nuts and Bolts and People”: Gender-troubled engineering identities. *Social Studies of Science*, *37*(3), 331–356. https://doi.org/10.1177/0306312706072175

Feigh, K. M., & Chua, Z. K. (2011). Panel Discussion on: Current State of Human Factors in Systems Design. *Annual Meeting of the Human Factors and Ergonomics Society*.

Fletcher, T. L., Fletcher, T. L., Williams, J. L., & Benedict, B. S. (2019). Minority Serving Institutions: America’s Underutilized Resource for Strengthening the STEM Workforce Report – Implications for Historically Black Colleges and Universities (HBCUs). *American Society for Engineering Education Annual Conference*.

Fletcher, T. L., Ross, M., Tolbert, D., Holly, J., Cardella, M., Godwin, A., & Deboer, J. (2017). *Ignored potential: A collaborative roadmap for increasing African American women in engineering [White paper].* http://www.nsbe.org/getattachment/News-Media/NSBE-News/ignored-potential/NSBE-Ignored-Potential-Whitepaper-2-27-17.PDF.aspx

Froyd, J. E., Wankat, P. C., & Smith, K. A. (2012). Five Major Shifts in 100 Years of Engineering Education. *Proceedings of the IEEE*, *100*, 1344–1360. https://doi.org/10.1109/JPROC.2012.2190167

Gasman, M., & Nguyen, T.-H. (2016). *Historically Black Colleges and Universities as leaders in STEM*.

Groen, C. J., Mcnair, L. D., Paretti, M. C., Simmons, D. R., & Shew, A. (2018). Exploring professional identity development in undergraduate civil engineering students who experience disabilities. *American Society for Engineering Education Annual Conference*.

Hughes, C. (2016). *Diversity Intelligence: Integrating Diversity Intelligence alongside Intellectual, Emotional, and Cultural Intelligence for Leadership and Career Development*. Palgrave MacMillan Publications.

Hughes, C. (2018). The role of HRD in using diversity intelligence to enhance leadership skill development and talent management strategy. *Advances in Developing Human Resources*, *20*(3), 259–262.

Hynes, M., & Swenson, J. (2013). The humanistic side of engineering: Considering social science and humanities dimensions of engineering in education and research. *Journal of Pre-College Engineering Education Research*, *3*(2), 31–42. https://doi.org/https://doi.org/10.7771/2157-9288.1070

James, S. M., & Singer, S. R. (2017). From the NSF: The National Science Foundation's Investments in Broadening Participation in Science, Technology, Engineering, and Mathematics Education through Research and Capacity Building. *CBE Life Sciences Education*, *15*(3).

Kochan, T., Bezrukova, K., Ely, R., Jackson, S., Joshi, A., Jehn, K., Leonard, J., Levine, D., & Thomas, D. (2003). The effects of diversity on business performance: Report of the diversity research network. *Human Resource Management*, *42*(1), 3–21.

Leonard, J. S., Levine, D. I., & Joshi, A. (2004). Do birds of a feather shop together? the effects on performance of employees' similarity with one another and with customers. *Journal of Organizational Behavior*, *25*(6), 731–754. https://doi.org/10.1002/job.267

Mcadams, D. A., & Kostovich, V. (2011). *A Framework and Representation for Universal Product Design*. *5*(1), 29–42.

McLoughlin, L. a. (2005). Spotlighting: Emergent Gender Bias in Undergraduate Engineering Education. *Journal of Engineering Education*, *94*(4), 373–381. https://doi.org/10.1002/j.2168-9830.2005.tb00865.x

Mitchell, D. J., Simmons, C. Y., & Greyerbiehl, L. A. (Eds.). (2014). *Intersectionality & Higher Education*. Peter Lang.

Mondisa, J. (2015). *In the Mentor's Mind: Examing the experiences of African-American STEM Mentors in Higher Education*. Purdue University.

National Academy of Engineering. (2018). *Understanding the Educational and Career Pathways of Engineers*. National Academies Press. http://nap.edu/25284

National Center for Science and Engineering Statistics. (2017). *Women, Minorities, and Persons with Disabilities in Science and Engineering*.

O'Dea, R. E., Lagisz, M., Jennions, M. D., & Nakagawa, S. (2018). Gender differences in individual variation in academic grades fail to fit expected patterns for STEM. *Nature Communications*, *9*(1). https://doi.org/10.1038/s41467-018-06292-0

Oldenziel, R. (1999). *Making Technology Masculine*. Amsterdam University Press. https://doi.org/10.1017/CBO9781107415324.004

President's Council of Advisors on Science and Technology. (2012). *Supporting the STEM Pipeline*. http://www.achieve.org

Pritchett, A. R., & Strong, A. C. (2016). Integrating Cognitive Engineering Into Industry Design Teams. *Journal of Cognitive Engineering and Decision Making*, 1555343416654082. https://doi.org/10.1177/1555343416654082

Reid, K. (2014). *Our Nation Needs to Fix the Breach in the STEM Pipeline*. National Society of Black Engineers Blog. https://www.nsbe.org/News-Media/Blogs/Karl-Reid/August-2014/Our-Nation-Needs-to-Fix-the-Breach-in-the-STEM-Pip.aspx

Rivera, L. A. (2012). Hiring as Cultural Matching: The Case of Elite Professional Service Firms. *American Sociological Review*, *77*(6), 999–1022. https://doi.org/10.1177/0003122412463213

Ross, M. (2016). *A Unicorn's Tale: Examining the Experiences of Black Women in Engineering Industry*. Purdue University.

Secules, S. (2017a). *Beyond Diversity as Usual: Expanding Critical Cultural Approaches to Marginalization in Engineering Education*. University of Maryland.

Secules, S. (2017b). Putting Diversity in Perspective: A Critical Cultural Historical Context for Representation in Engineering. *American Society for Engineering Education Annual Conference*.

Secules, S. (2019). Making the Familiar Strange: An Ethnographic Scholarship of Integration Contextualizing Engineering Educational Culture as Masculine and Competitive.

Engineering Studies, *11*(3), 196–216. https://doi.org/10.1080/19378629.2019.1663200
Secules, S., Gupta, A., Elby, A., & Turpen, C. (2018). Zooming Out from the Struggling Individual Student: An Account of the Cultural Construction of Engineering Ability in Undergraduate Programming Class. *Journal of Enginering Education*, *107*(1), 56–86. https://doi.org/10.18260/p.26239
Secules, S., Lee, W., Boyd-Sinkler, K., Masters, A., Hampton, C., Taylor, A., & Grote, D. (2019). Dilemmas in Co-Curricular Support: A Theoretical and Pragmatic Discussion on Current Practice and Future Challenges. *Collaborative Network for Engineering and Computing Diversity*.
Secules, S., Sochacka, N. W., & Walther, J. (2018). New Directions from Theory: Implications for Diversity Support from the Theories of Intersectionality and Liberatory Pedagogy. *The Collaborative Network for Engineering and Computing Diversity Conference*.
Seron, C., Silbey, S. S., Cech, E. A., & Rubineau, B. (2015). Persistence Is Cultural: Professional Socialization and the Reproduction of Sex Segregation. *Work and Occupations*, *43*(2), 178–214. https://doi.org/10.1177/0730888415618728
Shetterly, M. L. (2016). *Hidden Figures: The American Dream and the Untold Story of the Black Women Mathematicians Who Helped Win the Space Race*. Harper Collins.
Slaton, A. E. (2010a). *Engineering Segregation: The University of Maryland in the Twilight of Jim Crow*. *24*(July), 15–24.
Slaton, A. E. (2010b). *Race, rigor, and selectivity in US engineering: The history of an occupational color line*. Harvard University Press.
Slaton, A. E. (2015). Meritocracy, Technocracy, Democracy: Understandings of Racial and Gender Equity in American Engineering Education. In *International Perspectives on Engineering Education*. https://doi.org/10.1007/978-3-319-02904-7
Smith-Evans, L., George, J., Graves, F. G., Kaufmann, L. S., & Frohlich, L. (2014). *Unlocking opportunity for African American girls: A call to action for educational equity.*
Smith, J. M., & Lucena, J. (2016). Invisible innovators: How low-income, first generation students use their funds of knowledge to belong in engineering. *Engineering Studies*, *8*(1), 1–26. https://doi.org/10.1080/19378629.2016.1155593
Stevens, R., & Vinson, A. (2014). Institutional Obstacles to Ethnographic Observation in Engineering Industry. *American Society for Engineering Education Annual Conference and Exposition*.
Thomas, J. M. (2018). Diversity Regimes and Racial Inequality: A Case Study of Diversity University. *Social Curents*, *5*(140–156). https://doi.org/10.1177/2329496517725335
Tomlinson, F., & Schwabenland, C. (2010). Reconciling Competing Discourses of Diversity? The UK Non-Profit Sector Between Social Justice and the Business Case. *Organization*, *17*(1), 101–121. https://journals.sagepub.com/doi/pdf/10.1177/1350508409350237
U.S. Department of Education. (2017). *Integrated Postsecondary Education Data System (IPEDS)*.
United States Census Bureau. (2019). *QuickFacts*.
Weber, R. N. (1997). Manufacturing Gender in Commercial and Military Cockpit Design. *Science, Technology & Human Values*, *22*(2), 235–253.
Wilson, M. (2018). *The untold story of the vegetable peeler that changed the world*. Fast Company.
Yates, N., & Rincon, R. M. (2018). *Women of Color in the Engineering Workplace From Women*.
Zoltowski, C. B., Buzzanell, P. M., Brightman, A. O., Torres, D., & Eddington, S. M. (2017). Understanding the professional formation of engineers through the lens of design thinking: Unpacking thewicked problem of diversity and inclusion. *ASEE Annual Conference and Exposition, Conference Proceedings*, *2017-June*.