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MACROETHICS IN UNDERGRADUATE ENGINEERING: AN INSTITUTIONAL VIEW

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ABSTRACT

Engineering programs tend to focus on technical knowledge rather than developing ethical understanding. Those programs that do teach ethics typically focus on microethics, i.e. issues that arise in particular contexts and interactions between individuals, rather than macroethics, i.e. issues that address societal concerns more broadly. We conducted a systematic literature review of previous work assessing the inclusion of ethics education in undergraduate engineering programs. We used an institutional framework to understand where, in the context of their university experiences, undergraduate students are exposed to ethics. Through this analysis, we found that the most effective way to help students develop an understanding of macroethics is programming outside of the classroom. However, while equity and inclusion are key aspects of macroethics in the engineering profession, exposure to this topic is not accessible to all groups of students due to financial and time constraints that may preclude their participation.

KEYWORDS: Ethics, Macroethics, Institution, University, Undergraduate Education

INTRODUCTION

Undergraduate engineering programs tend to focus on technical knowledge in curriculum, often missing opportunities for helping students develop an understanding of the ethical dimensions of engineering work. More specifically, engineering students often have few opportunities for developing macroethical understanding. Rather, microethics, which is typically emphasized in the engineering profession, focuses largely on how individuals interact with one another responsibly and with integrity (Herkert 2001). For instance, Canon 4 of the American Society of Civil Engineers Code of Ethics states that engineers must avoid conflicts of interest and act "as faithful agents or trustees" to their clients and employers (ASCE 2020). This canon emphasizes the importance of decision-making within particular contexts and interactions between individuals, the key component of microethics (Doorn & Kroesen 2011).

In contrast, discussion of macroethics, which focuses on broader societal issues like impacts of climate change or issues of social justice, is largely absent from most engineering programs (Herkert 2001). Yet, it is imperative for engineers to engage with macroethics due to the unique position engineers have in impacting society through their work (Miller & Brumbelow 2016). For instance, in designing a stormwater drainage system for a new community, an engineer who understands macroethics is more likely to observe existing communities in the surrounding area to ensure they are not negatively impacted by the new development. This was seen in the Dove Springs neighborhood in Austin, TX, which has experienced increasing localized flooding over years as neighboring communities introduce more development including impervious pavement and commercial buildings (Caterine 2017). Dove Springs could have been protected at the start of the new development if engineers had anticipated the potential harmful effects on this lower income area with older infrastructure. Engineering thus directly impacts communities, and as such future engineers should understand how to conduct their work with societal implications in mind (Miller & Brumbelow 2016).

Here, we review the existing literature to examine factors found in previous work that impact ethical development amongst engineering undergraduate students. The literature observes both students' personal circumstances that may impact ethical views (e.g. gender, race, socioeconomic status), as well as institutional factors influencing how students approach ethics (coursework, student groups) (Bielefeldt and Canney 2016). While the influence of personal circumstances upon ethics is certainly important, we focus primarily on institutional factors here, with the goal of understanding how an emphasis on ethics within engineering education can lead to future engineers later implementing ethics in professional settings. With this in mind, we focus on exploring activities and common practices in undergraduate engineering education.

To explore the institutional framework, we use Scott's (2013) three pillars—the cultural-cognitive, normative, and regulative pillars. Doing so allows us to explore the cultures, actions, and rules within universities and engineering programs that impact student ethical development. The *cultural-cognitive* pillar describes how an institution can impact approaches to thinking and decision-making (Scott 2013). These cultural-cognitive elements of an institution are likely unique to that specific institution, and they often affect the members of the institution as a whole. They are unique attributes that make institutions distinct from one another; for instance, a large technical university will typically be quite different from a small liberal arts university in its culture and self-understanding. The *normative* pillar refers to expectations, obligations, and responsibilities understood within communities and sub-communities at an institution (Scott 2013). This pillar includes not only obligations and responsibilities that are expressly stated, but also the ones that are often unspoken yet expected of participants, such as fair distribution of work amongst members of a group project. The *regulative* pillar focuses on codified or written rules and their subsequent rewards and punishments (Scott 2013). Such rules allow for a clear understanding of expectations and requirements of participants at an institution. Within a university setting, an example of this pillar is codes outlining standards of academic integrity to control cheating or plagiarism. Together, these three pillars constitute the institutional factors that have the potential to impact ethical understanding and decision making. Our review focuses on identifying more specifically which of these institutional factors help engineering students to develop macroethical understanding.

METHODS

A systematic literature review was conducted using the Web of Science database (Web of Science 2020). Selection criteria of manuscripts surrounding institutional ethics in engineering are shown in Figure 1. The search terms ethics, morals, institution, university, and engineer were used in a topic search. Publication dates were restricted to the previous three decades (1990-2020) to capture more recent studies. Several healthcare terms—such as *genetic*, *medical*, and *health*—were excluded from the topic search to avoid skewing the results towards healthcare ethics and away from engineering education ethics. The final list of 14 articles represent a range of studies, while maintaining a focus on undergraduate engineering ethics education.

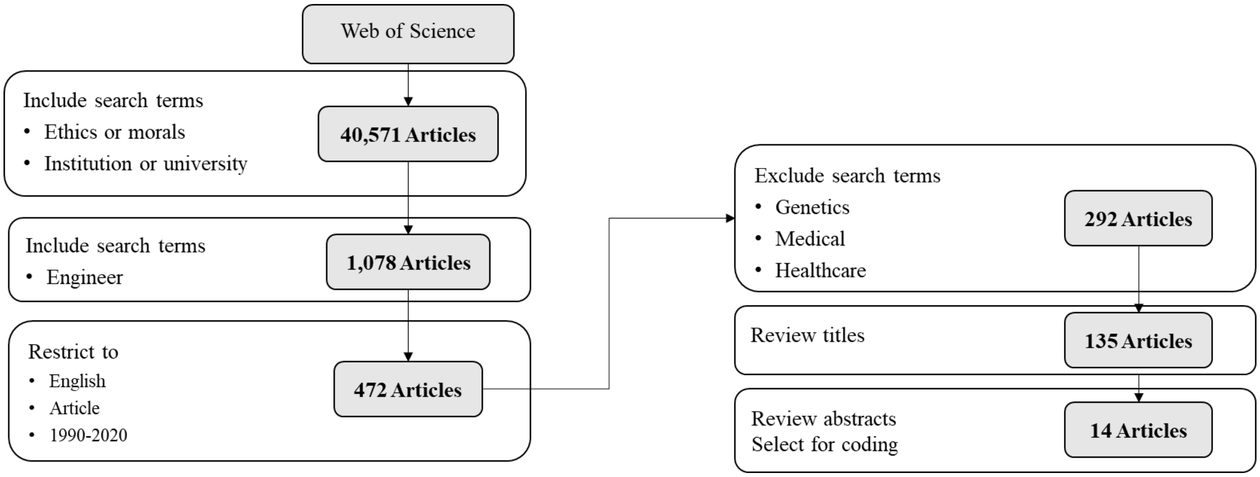

Figure 1. Selection of articles for qualitative analyses

Qualitative analyses were performed to identify thematic codes across the literature. Deductive coding was undertaken, beginning with the three institutional pillars: cultural-cognitive, normative, and regulative. From there, an inductive coding process (Elo & Kyngäs 2007) allowed relevant sub-codes to emerge within each pillar (see Table 1). Notably, the *normative* pillar was divided into three levels of sub-codes with inside-the-classroom and outside-the-classroom at the second level. Excerpts were coded from each paper when new information was presented—i.e., if one idea was discussed multiple times in different places in a manuscript, this was only coded once for that article. Frequencies are shown in Table 2.

Table 1. *Coding dictionary used in qualitative analyses*

Code	**Definition**	**Example**
Cultural-Cognitive	Qualities of an engineering program that influence decision-making	
University Type	How the university is classified according to properties such as size, research, and public status	"Some small differences were also noted between some of the institutions, with students at a military academy and a private university showing more positive [social responsibility] attitudes than students at a technically-focused institution and a medium-sized public institution" (Bielefeldt & Canney 2016).
Messaging	How a university advertises its programs to prospective students	"The ability of engineering to have positive impacts on society through service and green energy were more present on civil and environmental engineering websites" (Canney & Bielefeldt 2015).
Professor Attitudes	Emphasis placed on the importance of ethics by engineering professors	"We spoke to several faculty members at our site visit institutions who appreciate and convey to students the importance of practicing engineers' maintaining firm connections with the basic mission and broad impact of their work" (Colby & Sullivan 2008).
Normative	Activities that influence students' ethical expectations, obligations, and responsibilities	

Code	Definition	Example
Inside the Classroom	Methods of teaching ethical principles to engineering students in classroom settings	
Engineering Curriculum	How ethics is taught inside of regular engineering coursework	"An introductory engineering course is the most common setting in which students received ethics instruction" (Finelli et al. 2012).
Non-engineering Course	How engineering students learn about ethics in courses taught by non-engineering professors	"Wrestling with cases framed as moral dilemmas, either real or hypothetical, is also a staple of ethics courses offered through philosophy departments" (Colby & Sullivan 2008).
Upper Level Curriculum	How engineering students develop an ethical understanding in a senior design or capstone course	"Modules on engineering ethics and professional responsibility, typically consisting of two or three class sessions, most often in the capstone design course" (Colby & Sullivan 2008).
Case Studies	How specific historical engineering cases engage in learning about ethical issues	"These discussions range from references to well-known cases of engineering failure to classroom or homework exercises in which students grapple with tradeoffs between potentially conflicting values such as cost and safety" (Colby & Sullivan 2008).
Outside the Classroom	Activities, lessons that take place outside of a formal classroom setting	
Extracurricular	How a student's involvement in extracurricular activities, like Greek life and sports, impacts their ethical development	"When engineering students were involved in co-curricular experiences, they exhibited greater leadership skills, were more thoughtful on ethical decisions, and could articulate at a basic level how involvement influenced development" (Carpenter et al. 2014).
Community Service	How a student's community service experience impacts their ethical development	"Service-learning experiences challenged students' viewpoints on ethical decision-making and they returned to the classroom with broadened perspectives" (Burt et al. 2013).
Internships/Co-ops	How a student's internship experience impacts their ethical development	"Classroom conversations were richer when students shared incidents of witnessing unethical practices taking place at their out-of-classroom experience" (Burt et al. 2013).
Workshops, Seminars	How a training experience outside of regular coursework affects ethical development	"A seminar series was started, with an emphasis on speakers with service projects that they had completed, or with which they wanted help" (Passino 2009).
Regulative	Explicit statements or regulations that students or professionals must follow	
ABET Learning Outcomes	How an engineering program accomplishes the Accreditation Board of Engineering and Technology	"The proposed ABET outcomes suggest that students must be prepared to adopt a set of behaviors guiding their decisions as engineers" (Miller & Brumbelow 2016).
Professional Codes of Ethics	Whether an engineering program teaches the aspects of professional societies' Codes of Ethics	"Because ethics codes originate from within the profession, they provide a good sense of the kinds of ethical issues practicing engineers in various specialties are likely to confront" (Colby & Sullivan 2008).
Professional Licensure	Whether the engineering program emphasizes the importance of Professional Engineering licensure	"Most engineers are not licensed and thus have not explicitly sworn to uphold any of the profession's various codes of ethics" (Colby & Sullivan 2008).

RESULTS

Table 2 shows the frequency at which each topic appeared. The codes in the *cultural-cognitive* pillar account for 12% of the overall topics coded. The *normative* pillar covers 67% of the coded topics, divided into *inside the classroom* (51% of the normative codes) and *outside the classroom* (49% of the normative codes), revealing a relatively even split of topics. The *regulative* pillar includes the remaining 21% of coded topics.

Table 2. *Frequency of coded topics across literature review*

	Bielefeldt & Canney (2016)	Bielefeldt et al. (2018)	Burt et al. (2013)	Byrne (2012)	Canney & Bielefeldt (2015)	Carpenter et al. (2014)	Colby & Sullivan (2008)	Doorn & Kroesen (2011)	Finelli et al. (2012)	Miller & Brumbelow (2016)	Morrison (2019)	Passino (2009)	Porter (2016)	Siller et al. (2009)	**Total**
Cultural-Cognitive	5	6	1	1	6	1	5	1	0	1	2	2	0	1	**32**
University Type	3	1	1	0	1	1	1	0	0	0	0	0	0	0	**8**
Messaging	2	0	0	0	5	0	0	0	0	1	0	0	0	0	**8**
Professor Attitudes	0	5	0	1	0	0	4	1	0	0	2	2	0	1	**16**
Normative	11	16	15	4	3	11	18	8	35	6	8	21	10	9	**175**
Inside Classroom	5	8	2	4	0	6	16	8	20	1	8	8	2	1	**89**
Engineering Curriculum	2	5	1	2	0	3	6	1	10	1	3	7	0	1	**42**
Non-engineering Courses	1	0	0	0	0	1	3	1	3	0	0	0	2	0	**11**
Upper Level Curriculum	1	1	0	0	0	0	3	1	4	0	0	0	0	0	**10**
Case Studies	1	2	1	2	0	2	4	5	3	0	5	1	0	0	**26**
Outside Classroom	6	8	13	0	3	5	2	0	15	5	0	13	8	8	**86**
Extracurricular	1	3	3	0	0	2	0	0	6	4	0	0	1	1	**21**
Community Service	5	3	5	0	3	1	2	0	7	1	0	12	3	2	**44**
Internships/Co-ops	0	0	5	0	0	0	0	0	0	0	0	0	3	0	**8**
Workshops, Seminars	0	2	0	0	0	2	0	0	2	0	0	1	1	5	**13**
Regulative	2	6	0	3	0	2	15	1	4	5	5	9	0	3	**55**
ABET Learning Outcomes	1	1	0	0	0	1	4	0	1	3	1	3	0	3	**18**
Professional Codes of Ethics	1	3	0	3	0	0	10	1	3	2	4	6	0	0	**33**
Professional Licensure	0	2	0	0	0	1	1	0	0	0	0	0	0	0	**4**

DISCUSSION

Cultural-Cognitive Pillar

The codes pertaining to the cultural-cognitive pillar includes those that describe how a university or engineering program's culture can influence students' thinking and decision-making. From the literature search, we find that this pillar is the least studied of the three institutional pillars, likely because this pillar is more abstract than the other two pillars. The cultural-cognitive pillar is challenging to quantify because it is often unspoken and intangible; it is assumed as part of the background and taken for granted. It is often not until times of controversy and change that people begin to notice and question the cultural-cognitive features of an institution (Scott 2013).

The first code, University Type, looks at attributes such as size, research level, public status, etc. Bielefeldt and Canney (2016) find that students' sense of social responsibility decreased over time at some universities (technical public, private, and military) but increased over time at others (large public and medium public). This suggests that there are university characteristics that can improve students' understanding of ethics.

University and program messaging help constitute this pillar. Public messaging that uses macroethical images and word choices can impact recruitment to the University's engineering programs. Such messaging might include references to the environment, to social issues, or to public health. (Canney & Bielefeldt 2015). As a result, it can impact the demographics of the students who attend the university. Research shows that female prospective students tend to respond more positively to this messaging than male prospective students, which can significantly impact the gender balance of an engineering program (Bielefeldt & Canney 2016). If students are already more ethically conscious upon entering the university, they can influence the culture of the engineering program over the course of their education. This may include advocating for more socially responsible topics in the curriculum or creating student organizations that focus on community involvement. Upon graduation, these engineers can contribute to a more equitable workplace and engineering industry at large.

The attitudes of engineering professors toward teaching ethics also contributes to the cultural-cognitive context. Typically, professors can choose how much time is invested in ethics education in their courses, as they determine the specific content that is covered (as long as it meets the course objectives). As students expect professors to teach skills to be successful after graduation, it follows that students' attitudes towards ethics will be greatly influenced by that of their professors and whether it is incorporated into class content. Students who believe that macroethics is important while they are in school are more likely to continue this belief in their profession.

The Normative Pillar

The codes pertaining to the normative pillar include those that relate to the expectations and obligations, often unstated, of members within an institution (Scott 2013). We focus primarily on the settings and actions in which students may learn about macroethical topics and develop macroethical understanding. For coding purposes, these settings and actions are divided into two categories: inside the classroom and outside the classroom.

Inside the Classroom

Engineering students can be exposed to macroethics in engineering or non-engineering classes. As discussed above, some engineering professors choose not to include macroethics in their course content, and rather focus exclusively on the technical aspects of the course objectives (Bielefeldt et al. 2018). Some engineering departments choose to fulfill ethics requirements by requiring ethics classes in other departments. Colby and Sullivan (2008) argue that while a philosophy course may be rich in ethical theory, engineering students in these situations often miss out on the engineering context that would allow them to connect the theory to their studies in engineering. If, for instance, engineering students discussed macroethics in a transportation course, they could discuss the positive impact engineers can have on a community by improving pavement or redesigning roads so that they are safer and more accessible. They could even consider the impacts of public transportation access for low-income neighborhoods, leading to a more equitable community.

Many engineering courses include case studies to teach engineering ethics. These case studies often relay the story of a failed infrastructure project that resulted in deaths and financial loss (Byrne 2012). Doorn and Kroesen (2013) argue that case studies are effective because they relate technical engineering concepts to tangible ethical issues. These real-world scenarios allow students to practice the decision-making that will be necessary as professionals. They further argue that case studies are especially important for engineering students because their work includes many stakeholders who may be impacted by their decisions. Working through a case study, students can consider the safety implications for construction workers, for instance, which they will hopefully translate into practice once they go out into the field.

However, these engineering case studies often focus primarily on microethics—singular moments of decision and interpersonal interactions. Morrison (2019) argues that the case studies most often used in engineering curricula rely too much on moments of disaster, removing the real-world context from the study. For instance, a case study often used in engineering curriculum, the 1986 Challenger Explosion, is an example of this approach (ASCE 2020). Students read about key decisions made by a single engineer and his interactions with several colleagues. This case study also typically includes a synopsis of the technical errors that caused the explosion. While this case study presents an important moment in history, it does not address macroethical issues. An alternative case study to address macroethics might discuss day-to-day issues such as zoning restrictions. A case study could present the challenges faced by low income residents of a neighborhood zoned exclusively for single family homes. Multi-use zoning is an alternate approach that enables residents to live within walking distance of grocery stores, doctors' offices, and public transit. A case study such as this one could include an activity to determine the most equitable zoning structure for a given neighborhood, enabling the students to explore macroethical concepts in city planning.

Outside the Classroom

Activities that take place outside of the classroom can significantly impact students' ethical development. The literature shows that even more than formal coursework, outside the classroom activities can teach students about macroethics and its importance in the engineering profession (Burt et al. 2013). For instance, Carpenter et al. (2014) found that students involved in extracurricular activities "were more thoughtful on ethical decisions and could articulate at a basic level how involvement influenced development". The activities that emerged in the literature as being most influential to students' understanding of macroethics were community service, internships, and workshops.

Many extracurricular activities include a service component where students have the opportunity to work within their community (e.g., Habitat for Humanity) or communities worldwide (e.g., Engineers without Borders). After completing such service, students are more likely to recognize the positive impact that engineering can have on society. Burt et al. (2013) discuss the value this service work can bring to a student's ethical development, arguing that participation in engineering-oriented community service allowed students to connect the engineering profession to macroethics and the responsibility of engineers. Further, community service tends to be an activity that students not only learn from but enjoy. In fact, Canney and Bielefeldt (2018) write that an emphasis on service within an engineering program contributes to student retention, "especially for women and underrepresented minority students". A diverse student population will likely result in a diverse workforce, which is especially important when working in communities that reflect that diversity. Research shows that women and underrepresented minority engineers are more likely to understand the needs of community members who are like them. For instance, a 2014 study in Sweden observed the effects of traditional snow removal practices from a gender perspective. The study found that men benefited more when municipalities removed snow from highways before clearing sidewalks and local roads. Women, who more often walked, biked, or used public transportation, experienced more delays and injuries in these traditional circumstances. By switching the order of snow removal to walkways, then local roads, then highways, the community experienced a decrease in hospitalizations, vehicle accidents, and delays (SKR Jämställdhet 2014). This is significant because issues like this are not typically addressed until women and underrepresented minorities are involved in decision-making. By ensuring that these groups are retained in undergraduate engineering programs, we can ensure a more diverse workforce for the future.

Internships and co-op programs can also contribute to the development of macroethical understanding. These experiences expose students to real ethical dilemmas and decisions faced by professionals (Burt et al. 2013). In the construction management field, for example, student interns often visit or work on jobsites where they can interact with construction workers, an experience that may emphasize the need for safe working practices. Civil engineering interns may have an opportunity to visit communities affected by their work; for instance, if an engineering firm is tasked with designing a new luxury high-rise, visiting the site might provide an opportunity to see the affordable housing units that will be replaced. For some students, that might encourage them to seek employers who build affordable homes, schools, or other public benefit.

Workshops and seminars provide another important vehicle for students to develop ethical understanding outside of a classroom. These events often include guest speakers who are industry professionals, covering topics outside of the formal engineering curriculum. Siller et al. (2009) discusses that a benefit of these programs is that they are not confined to course objectives and can instead cover interesting topics to help students expand their understanding. For instance, a speaker might present a new technological innovation that is transforming the renewable energy sector. Or a developer might present plans for a mixed-use residential complex that provides a range of housing options for a diverse population. These workshop settings also provide an opportunity for students to meet professionals who may have a different background from their peers or their professors. This may be especially beneficial for underrepresented students who might not have previously had a role model in their field to whom they could relate. Seeing someone who looks like oneself in a successful position can encourage a person to enter the engineering profession upon graduation, contributing to a newly diverse workforce. Research and development often benefit from a diverse team. In 2017, for instance, a Nigerian tech worker showed an automated soap dispenser that did not work when he waved his hand below it because it had been programmed (presumably inadvertently) only to respond to lighter skin tones (Afigbo 2017). This example demonstrates the oversight that can occur when diversity is ignored in technology and engineering. When representation becomes a priority, technology will be designed in a more inclusive way.

Community service, internships, and workshops are all thus valuable experiences to enhance students' understanding of macroethics. However, Porter (2016) argues that another step needs to be taken by reflecting on these experiences in a classroom setting. Burt et al. (2013) further discusses the value of debriefing in a classroom because of the transformation "into a realtime case study for students to share how they would handle the dilemma if they were faced with a similar issue." The greatest benefit in this discussion is the value it brings to students who were not able to attend the service event, participate in the internship, or attend the workshop. It is important to note that these activities are not accessible to everyone. Often there are equity issues associated with obtaining internships including cost of travel and housing, professional connections, or in some cases the ability to take unpaid internships. Community service and workshops both take time outside of typical class hours, potentially eliminating the opportunity to attend for those with families, jobs, or transportation limitations. However, when students can spend time at these activities, it can transform their classroom discussions into real-life examples/case studies. This further supports Doorn and Kroesen's (2013) position that case studies are useful educational tools inside the classroom. Rather than reading and discussing a case study from someone else, students can bring their own experiences to support their learning inside the classroom.

The Regulative Pillar

The regulative pillar typically plays a key role in engineering ethics curricula by establishing rules and standards. Professional Codes of Ethics are created and upheld by engineering societies and often outline ethical expectations of practicing engineers. Colby and Sullivan (2008) discuss that many professional societies' Codes of Ethics "acknowledge the overall mission of the profession as contributing to human welfare." If students can learn this important aspect of engineering early in their education, they are more likely to view all of their work through this lens for the duration of their career. Colby and Sullivan continue that codes "make it clear that engineering competence is inseparable from the ethical dimensions of the work." This is significant because Codes of Ethics are written documents that hold practicing engineers to a high standard. To ensure ethics are taught as a standard across all engineering programs, the Accreditation Board for Engineering and Technology (ABET) outlines this expectation as a learning outcome for students in accredited engineering programs (ABET 2018). This is important so that all engineering students, regardless of which university they attend, are exposed to ethics during their undergraduate education. This standard is limited, though, as the outcome does not specify how to teach ethics in any great detail.

CONCLUSION

Macroethics is an important aspect of the engineering discipline that is often overlooked. In this systematic literature review, we analyzed the existing research on how macroethics is learned in undergraduate engineering programs. We found that experiences outside of a classroom, such as community service and internships, are more effective than traditional approaches used in most programs. While equity and inclusion are key aspects of macroethics in the engineering profession, we also found that experiences to learn about this outside of a classroom have their own unique barriers. Oftentimes women and underrepresented minority students face additional challenges such as childcare, jobs, and transportation. There needs to be an effort to eliminate these barriers so that underrepresented students can excel and ultimately join the engineering profession where they can make informed decisions based in macroethics.

An opportunity for future research is to explore the impact of diversity on an engineering program. Research in this realm so far simply shows who is more ethical; for instance, Bielefeldt and Canney (2016) found that female engineering students tend to score higher in social responsibility than male students. It would be interesting to explore the effect of a gender balanced learning environment on students' understanding of macroethics. Do male students develop a great ethical understanding from working with and learning from female students? Of course, this could also be studied on ethnicity, race, and socioeconomic background. The benefits of diversity in technology and engineering are boundless. Whether it is snow removal, updating water infrastructure, zoning for affordable housing, or designing automatic soap dispensers, underrepresented minority engineers play a key role in designing and planning an equitable future.

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