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ORIGINAL ARTICLE

Resisting and assisting engagement with public welfare in engineering education

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Abstract

Background: Increasing engineering students' engagement with public welfare is central to promoting ethical responsibility among engineers and enhancing engineers' capacity to serve the public good. However, little research has investigated how student experience attempts to increase engagement with public welfare concerns.

Purpose/Hypothesis: This study identifies and analyzes the challenges facing efforts to increase engineering students' engagement with the social and ethical implications of their work through a study of students' experiences at two engineering programs that emphasize public welfare engagement.

Design/Methods: We conducted interviews with engineering students ($n = 26$) and ethnographic observations of program events, classes, presentations, and social groups ($n = 60$) at two engineering programs that focus on engagement with public welfare and foreground learning about the social context and social impacts of engineering. We analyzed these data to identify areas in which students experienced challenges integrating considerations of public welfare into their work.

Results: We found that four main areas where engineering students experienced difficulty engaging with considerations of public welfare: (a) defining and defending their identities as engineers; (b) justifying the value of nontechnical work and relevance to engineering; (c) redefining engineering expertise and integrating community knowledge into projects; and (d) addressing ambiguous questions and ethics.

Conclusions: This work contributes to knowledge about the barriers to increasing students' engagement with issues of public welfare, even when programs encourage such engagement. These findings are relevant to broader efforts to increase concerns for ethics, social responsibility, and public welfare among engineers.

KEYWORDS

ethics, philosophy of engineering education, public welfare, qualitative, social responsibility

1 | INTRODUCTION

> The issues that divide or unite people in society are settled not only in the institutions and practices of politics proper, but also, and less obviously, in tangible arrangements of steel and concrete, wires and transistors, nuts and bolts.
>
> Langdon Winner, 1980. "Do Artifacts Have Politics?"

Engineers have a great capacity and a great responsibility to contribute to many areas of life. From the smallest nanotechnological medical devices to massive infrastructure projects, engineers shape labor, leisure, commerce, travel, and health. Developing engineers to serve the utmost public good involves critical inquiry into the social, political, and ethical impacts of engineering. However, engineering has typically been characterized by a hierarchical and dualistic approach that values technical and mathematical knowledge over social, cultural, or political knowledge (Cech, 2013, 2014; Faulkner, 2000, 2007; Leydens & Lucena, 2018; Nieusma, 2013; Riley, 2008). This hierarchy shapes how engineers take responsibility for the social impacts of engineering practice as well as the ability of engineers to serve public welfare (Cech, 2013, 2014; Leydens & Lucena, 2018; Nieusma, 2013; Riley, 2008).

Furthermore, while there have been efforts to increase engagement with public welfare in engineering education—such as the Year 2000 revision of the ABET accreditation standards to emphasize social context and ethical responsibility in engineering—recent longitudinal research demonstrates that students express *declining* concern for ethics, social responsibility, and the social impacts of technology over the course of their engineering education (Bielefeldt & Canney, 2016; Cech, 2014). This shift indicates that during their engineering education, students may be deterred from considering issues of public welfare as an integral part of engineering, with critical consequences for the ability of engineers to ethically serve society (Cech, 2014).

Our study identifies barriers to fostering students' engagement with issues of public welfare during the course of their engineering education. We ask, what types of challenges do engineering students face when considering issues of public welfare and how do they address these challenges? Following Cech (2014), we use the phrase "engagement with public welfare," which Cech explains "is meant to be a broad term encompassing engineers' general reflexivity about how their work influences the national (and perhaps global) lay 'public,' both positively and negatively" (p. 44). Engagement with public welfare involves seeking an understanding of the complex beneficial and detrimental effects that engineering has on society. This engagement encompasses concerns about social justice as well as the development of a sense of ethical responsibility to use engineering to serve the public good (Cech, 2014).

We conducted interviews and observations at two engineering programs that explicitly foreground student engagement with issues of public welfare, including learning about the social context and social impacts of engineering, addressing concerns of social inequality, and considering practical and ethical issues that arise when working with communities on engineering projects. Since these programs represent strong, well-established efforts to develop student engagement with public welfare, they valuably cast into sharp relief the challenges facing broader efforts to foster considerations of public welfare throughout engineering education. We found that emphasizing engagement with public welfare disrupts the dominant technocentrism in engineering and unsettles boundaries of engineering identity, practice, knowledge, and ethics—creating challenges for students to engage with public welfare concerns. As we elaborate below, we identified four main areas where engineering students experienced difficulty engaging with considerations of public welfare: (a) defining and defending their identities as engineers; (b) justifying the value of nontechnical work and relevance to engineering; (c) redefining engineering expertise and integrating community knowledge into projects; and (d) addressing ambiguous questions and ethics. Attending to these aspects will help strengthen efforts to increase engagement with public welfare among engineering students and in engineering practice.

2 | CRITICAL PERSPECTIVES ON ENGINEERING EDUCATION

Research on engineering education has found that normative conceptions of engineering have marginalized engagement with public welfare issues (Cech, 2013, 2014; Godfrey & Parker, 2010; Leydens & Lucena, 2018; Nieusma, 2013; Riley, 2008). This marginalization includes a hierarchical, dualistic sense of knowledge that values the technical over and apart from the social (Cech, 2013, 2014; Faulkner, 2000, 2007; Leydens & Lucena, 2018; Nieusma, 2013; Riley, 2008). This dominant conception of engineering as technical problem-solving, created through the objective, rational, and logical application of scientific principles, discourages student engagement with public welfare concerns (Godfrey & Parker, 2010; Pawley, 2009; Riley, 2008). Cech (2014) argued that a central pillar of thought in engineering is the "ideology of depoliticization," which frames "'non-technical' concerns such as public welfare as irrelevant to 'real' engineering work" (p. 45).

This devaluation of nontechnical knowledge has significant social and ethical implications as it restricts reflective engagement about the social implications of engineering itself, such as what is engineering for, who is engineering for, and what are the larger impacts of technology in society (Cech, 2013, 2014; Conlon, 2008; Downey, 2005; Herkert, 2000; Nieusma, 2013; Riley, 2008; Zandvoort, 2008;). These kinds of macro-ethical issues require going beyond technical problem-solving to interrogate the broader purpose of engineering and to reflect upon how engineering may have complex, contradictory consequences for public welfare—alleviating some problems while at times exacerbating others.

These ethical issues point to the challenges of fostering student engagement with concerns of public welfare in engineering education. Despite the stated purpose of engineering to serve the public good (NSPE, 2018a), the technocentric focus of engineering curtails engineers' abilities to critically engage with the complex social, political, and ethical implications of their work. Students who are exposed to more explicit emphasis on public welfare issues may be forced to contend with conflicting messages about the relevance and value of these ideas to their roles as engineers (Cech, 2014). If public welfare is considered, it may be thought of as a self-evident effect of technology, rather than something that can be critically interrogated through questioning: which public, whose welfare, and under what conditions?

2.1 | The politics of objectivity

The technocentrism of engineering produces a dual effect where, on one hand, it restricts engineers from critically engaging with the social implications of their work; and on the other hand, it conceals how engineering is already embedded in social relations. The emphasis on positivist epistemologies that centralize objectivity and logic are in and of themselves cultural aspects of engineering that have important consequences (Cech, 2013; Riley, 2008). First, the reliance on positivist epistemologies marginalizes other forms of knowledge such as reflexive, cultural, or experiential knowledge. In addition, feminist research on science emphasize how knowledge itself is produced within particular social relations (Haraway, 1988; Harding, 1992; McCorkel & Meyers, 2003; Naples, 2003). Conceiving of engineering as the objective application of scientific principles obscures how engineering knowledge and practice is deeply political (Cech, 2013) and is shaped by relationships with industry (Johnston, Lee, & McGregor, 1996) and government, including military and extractive industries that have strong social and environmental consequences (Riley, 2008).

Military and extractive influences in engineering are not the only ways that technology is embedded in social structures and power relations. As Winner (1980) argued, technologies are integral to the structure of society through their roles in shaping labor, communication, mobility, and consumption. In that respect, he argued that technologies are "similar to legislative acts or political foundings that establish a framework for public order" (Winner, 1980, p. 128). All fields in engineering, therefore, are implicated in the social order of society. The conception of engineering as the objective application of scientific principles obscures how engineering is both shaped through social relations of power and produces particular social relations of power. In other words, engineering has never been value-neutral, in part *because of*—not despite—its persistent emphasis on objectivity, scientific laws, and measurable facts. Explicit engagement with the social context and impacts of engineering is necessary to understand how engineering may contribute to—or detract from—public welfare concerns.

2.2 | Efforts to increase engagement with public welfare in engineering

As engineers have great capacity to impact society both positively and negatively, many engineering educators have advocated for a more explicit emphasis in engineering education on social justice, ethics, and other considerations of how engineering affects social wellbeing (Leydens & Lucena, 2018; Lucena, 2013; Riley, 2008). These efforts challenge the technocentric focus of engineering and positivist approaches to problem solving by treating reflexive engagement with the social context and impacts of engineering as essential to addressing public welfare issues.

Some scholars have addressed the need for more explicit emphasis on the social and ethical implications of engineering by advocating for interdisciplinary training in areas such as law, ethics, politics, sociology, critical pedagogy, and history in engineering education (Adams et al., 2011; Cumming-Potvin & Currie, 2013; Kline, 2001; Zandvoort, 2008). Other educators and researchers have called for self-reflection on the ways that biases, power, and privilege shape engineering (Adams et al., 2011; Baillie & Armstrong, 2013; Riley, 2008). Additionally, educators and researchers have advocated for critical reflection on how engineers define problems, not just solve them (Downey, 2005), and for greater discussion about what engineering is for, who it is for, and how the benefits and costs of technology are disproportionately distributed in society (Bucciarelli, 2008; Conlon, 2008; Herkert, 2000; Riley, 2008).

There has also been a rise in engineering programs that explicitly focus on using engineering to improve global social welfare, training engineers to address global inequalities and development. Several prominent institutions have developed programs such as Stanford's Global Engineering, the University of California at Berkeley's Development Engineering, MIT's global-poverty-focused D-Lab, Colorado School of Mines' Humanitarian Engineering, University of Colorado-Boulder's Global Engineering, and Purdue's Humanitarian Engineering, to name a few. The rise in prevalence of these programs reflects a broader interest in engineering education to engage with the public good.

However, there has been little research on how students actually experience the efforts made by many engineering education programs to engage students in public welfare issues. Previous research has used classroom exercises, such as analysis of student essays, to demonstrate increased public welfare engagement among students who take classes with more explicit emphasis on social issues in engineering (Leydens & Lucena, 2018; Schneider & Munakata-Marr, 2013). Yet, these methods provide only a partial understanding of the processes through which students develop conceptions of public welfare issues and integrate these principles into their understanding of what good engineering practice entails.

Furthermore, other research complicates these classroom-based studies. Cech's (2014) longitudinal study of more than 300 engineering students in four different programs found that, even in programs that widely emphasized public welfare issues, student concern with public welfare declined over the course of their college careers. Cech's (2014) study, which used survey data, called for more research and ethnographic study to understand the processes through which this disengagement with public welfare may be occurring.

Bielefeldt and Canney's (2016) survey of engineering students' attitudes of social responsibility also demonstrated that students were more likely to decrease than increase social responsibility attitudes during their engineering studies. In particular, they found that students' sense of moral responsibility to help others through engineering declined pronouncedly over time (Bielefeldt & Canney, 2016). Relatedly, Rulifson and Bielefeldt (2018) found that students in the latter part of their undergraduate engineering education valued company profit above public safety or making a positive impact on society, and showed decreased interest in serving marginalized populations. Participating in community service and taking courses that emphasize how engineering can benefit society are associated with attitudes of greater social responsibility, yet the precise processes through which these classes and activities impact students' engagement with public welfare remain unclear (Bielefeldt & Canney, 2016; Rulifson & Bielefeldt, 2018). Thus, more research is needed to explain why students are—or are not—learning to value public welfare in engineering.

Furthermore, Rulifson and Bielefeldt's (2017) interview-based study indicates that students who are more interested in explicit engagement with public welfare may leave engineering majors entirely. The authors argue that the 40% dropout rate among engineering majors is partially attributable to students feeling as though they could have a clearer social impact through non-engineering majors. Therefore, engagement with public welfare may assist with student retention in engineering in addition to increasing benefits to society.

These recent studies compel us to further investigate the barriers to increasing engineering students' concerns for public welfare. We ask, what types of challenges do engineering students face when engaging with issues of public welfare, and how do they address these challenges? We approach these research questions through a qualitative study of two engineering programs that explicitly foreground student engagement in public welfare issues and concerns for the social context and social impacts of engineering. As these are cases of strong, well-established efforts to increase engagement with public welfare, they are valuable settings for identifying the challenges associated with integrating considerations of public welfare into engineering education because they illustrate the barriers to change even in highly supportive circumstances. Understanding how students are deterred from public welfare engagement in engineering provides crucial insights into how to improve the ethical and social responsibility of future engineers.

3 | METHODS

This research explores how students adopted, rejected, and grappled with public welfare engagement efforts in two engineering programs. We approach our analysis from the standpoint that engineering education is not just the transmission of information but also a social process of enculturation through which students learn particular values, actions, and perspectives through both explicit and implicit means (Bejerano & Bartosh, 2015; Stonyer, 2002). We selected two programs to study that explicitly emphasized the social context of engineering, integrating community knowledge and perspectives, understanding the social impacts of technology, and using engineering to address social inequalities and enhance social welfare.

We studied undergraduate, masters and PhD students at one public and one private university. To maintain the anonymity of our study programs and participants, we provide only general details of the programs, students, and curricula as necessary to support our findings. Coursework in both programs focused on topics that are not typical in engineering, such as community development, human-centered design, global inequalities, and social justice. Undergraduate, masters, and PhD students all took courses in these programs and also participated in various types of applied work, through internships, research, or coursework-based projects. Some, but certainly not all, graduate students had also attended undergraduate engineering programs with an explicit social focus. Students in both of these programs also took engineering classes outside of their programs and received degrees in departments such as civil engineering or environmental engineering. As such, students were exposed to dominant engineering cultural norms (ways of acting) and epistemologies (ways of thinking and knowing) while also being exposed to alternative norms and knowledge through courses that foreground issues of public welfare and social inequality. Therefore, these cases provide an important opportunity to observe how students navigate and resolve tensions between these competing frameworks of engineering knowledge and practice. Moreover, because these are relatively extreme cases of efforts to increase student engagement with public welfare issues, they readily reveal barriers to change in the *best* of circumstances—where programs prioritize and emphasize such training. In so doing, our findings illuminate constraints that engineering students from all fields may encounter when considering public welfare and that other engineering programs hoping to increase student engagement in public welfare will need to consider.

This research included 26 in-depth interviews with students and 110 hr of observation of 60 different program events. The student interview respondents included six undergraduate students, nine Master's students, and nine PhD students (See Appendix A for a description of our interview respondents). Nineteen students were represented from one institution and five students from the other institution. The majority of the students we interviewed were enrolled in civil or environmental engineering degrees, which was reflective of the greater representation of these subfields in the programs we studied. One reason for the high representation of students in these fields may be attributed to an overlap between the program curricula and the requirements to complete civil or environmental engineering degrees. Additional research should explore what other factors attract or deter students from pursuing these types of programs and how experiences may be different for students in other engineering fields. Furthermore, the purpose of this study is not to do a specific comparison of these two institutions nor an in-depth study of one particular institution but rather to identify themes that resonate across institutional context. For this reason, we also do not engage in an analysis of the differences between undergraduate, PhD, and masters students; however, future research should examine potential differences among these groups in more detail.

In a recent guest editorial in the *Journal of Engineering Education*, Pawley (2017) calls for more explicit attention to how race and gender impact research findings. In Appendix A, we list the gender and degree of each respondent. Because we did not collect additional demographic data such as students' self-identified racial identity or socioeconomic status, we are unable to make a precise comparison of the demographics within these programs compared to engineering more broadly. Furthermore, identifying some students' racial identities may be impossible to do while also maintaining their confidentiality. However, the demographics of the students we interviewed and observed are similar to the overall demographics of the programs that we studied. Based upon our observations, we estimate that women comprise at least half of the students in these programs and that a large majority of the students are white. Thus, these programs appear to represent more gender diversity but less racial diversity than engineering as a whole. Prior research has indicated that programs which provide more explicit engagement with the social impacts of engineering may attract and retain more women (Litchfield & Javernick-Will, 2015; Rulifson & Bielefeldt, 2018). However, the ways in which socioeconomic status, gender, and race intersect and affect students' experiences, recruitment, and retention in these programs are important, yet understudied, aspects of these programs, and certainly merit future analysis.

The interviews averaged around 1.25 hr and were semi-structured to allow students to share perspectives and issues that were important to them rather than limiting the study to what the researchers believed was relevant (Rubin & Rubin, 2005; see Appendix B for a description of our interview protocol and core interview questions). In our analysis, we have altered identifying information such as the names of people and places to protect student and program confidentiality, and have excluded specific descriptions of students to maintain internal confidentiality by minimizing the possibility that students could be identified by members within their own program (Tolich, 2004). We edited the interview transcriptions for grammatical clarity (e.g., deleting false starts and filler words such as "um" and "like") without changing the substantive content or meaning of quotations.

We conducted observations at 60 different program events, including classes, program-sponsored social events, presentations, and group activities (47 at one institution, and 13 at the other). Observations ranged from 1 to 10 hr. We wrote field notes drawing upon guidance from Emerson, Fretz, and Shaw (2011) to take note of what appeared important or contentious to those being observed, what was surprising, and non-verbal as well as verbal cues and interactions. We also linked our observations with our interviews so that we were able to follow up about something that stood out, was unclear, or was surprising in an observation in order to hear a more in-depth perspective on that subject.

We transcribed and coded our interviews and field note data from observations, using qualitative analysis software, in order to develop salient themes from the data (Saldaña, 2016). Because our approach to the qualitative content analysis was inductive, we achieved reliability and validity through the coding exercises and theme development strategies discussed below. All authors participated in a coding exercise where we analyzed the same subset of interview transcripts and observation field notes, coding for specific themes related to public welfare, engineering identity, scope of work, and ethics, in addition to novel codes. We then compared our codes, and resolved any differences between our approaches. The lead coder regularly wrote analytic memos (Saldaña, 2016) and discussed themes and memos during team meetings, which occurred weekly between two of the team members and monthly with the entire research team (see Appendix C for a flowchart of the coding process).

Coding, analytic memo writing, and reflection took place iteratively, in keeping with inductive approaches to theme building (Emerson et al., 2011; Saldaña, 2016). As our team is an interdisciplinary group consisting of scholars from engineering, sociology, urban planning, and environmental design, we enriched our analysis by integrating our diverse disciplinary approaches from both within and outside of engineering. For further validation, during the process of data analysis, the researchers shared general findings with a limited number of the students in the programs that we studied in order to receive feedback. This exchange facilitated input from researchers and research participants in the process of analysis.

4 | RESEARCH FINDINGS

We found that students experienced great enthusiasm when engaging with the societal impacts of engineering and considering how best to use engineering to promote public welfare. Indeed, several students stated that they may not have stayed in the engineering field had it not been for their educational experiences engaging with public welfare issues. These students' decisions indicate that there is a desire for more engagement with public welfare issues in engineering education.

However, we also found that students experienced significant conflicts and frustrations when engaging with public welfare. Foregrounding issues of public welfare in engineering challenged the technical/social dualism in engineering that both separates the technical from the social and also privileges technical work over social concerns such as public welfare. By emphasizing public welfare engagement, these programs and students engaged in boundary work (Lamont & Molnar, 2002) that unsettled notions of what it means to be an engineer, what engineers do, and what constitutes engineering knowledge and expertise. This created difficulties for students as they contended with conflicting conceptions of engineering knowledge and practice.

We examine and identify these challenges as (a) defining and defending students' identities as engineers; (b) justifying the value of nontechnical work and relevance to engineering; (c) redefining engineering expertise and integrating community knowledge into projects; and (d) addressing ambiguous questions and ethics. In the sections below, we outline each of these areas in more detail. In Section 5 we also highlight practices that increase engagement with public welfare issues.

4.1 | Defining and defending identities as engineers

Engineering education is a critical site of identity formation and the establishment of professional values. As Meyers, Ohland, Pawley, Silliman, and Smith (2012) and Stonyer (2002) established, claiming an engineering identity is a central part of integrating into an engineering community, and we argue that it is also key to legitimizing engagement with public welfare. What it means to be an engineer plays a large role in delineating the scope of engineering practice and engineers' ethical responsibilities to society (Downey, Lucena, & Mitcham, 2007). Tonso (2006) argued that developing an engineering identity involves a relational process of both self-identifying as an engineer as well as being identified by others as an engineer. In our study, students expressed that they had to defend engagement with public welfare as a legitimate aspect of "real engineering" and their identities as legitimate engineers. For these students, establishing an identity as an engineer involved navigating a dualism that frames engineers as highly technical people and that deems anything outside of the "technical" to be either of lesser value or outside the scope of engineering.

One strategy that students used to justify engaging with public welfare issues was to critique dominant conceptions of engineers as overly technical, to a fault. As one student put it:

> Engineers are all focused on efficiency: cost efficiency and design efficiency. Sometimes when I see engineers, they're just so proud of their math and science skills, and it's like, "You're not really like human though. You're more like a robot! You have all these numbers and things, but interacting with people, designing things for people, that's something that you also need to have."

Another student echoed this sentiment by describing how, because his program is focused on considering the social implications of engineering, he is able to be more like a "human being who also knows how to do math, rather than a calculator who also has to talk to people at the coffee shop."

Critiquing normative conceptions of engineers was an important mechanism through which students validated critical engagement with the public good in engineering. As another student explained:

> Our brains aren't just math and science. We're not just robots. We have that human side to our designs—that human-centered design approach, where we understand the social needs and the needs outside of technology.

By distinguishing engineers who are engaged with public welfare concerns from "robots," this student's statement illustrates how breaking from normative, "robotic" engineering identity enables students to engage with the social implications of engineering.

Other students rejected or distanced themselves from engineering identities, saying that they do not feel "purely engineer," or that they do not want to be "just an engineer." This is similar to findings from Litchfield and Javernick-Will (2015), who highlighted how engineering students may take on additional identities beyond "engineer" to encompass work and values related to public welfare concerns. However, rather than transforming the identity of what it means to be an engineer, this positioning leaves the technocentric emphasis of engineering identity intact. Since what it means to be an engineer plays a large role in delineating engineering ethics and practice (Downey et al., 2007), this represents a barrier for the adoption of broader engagement with public welfare in engineering as a whole.

Furthermore, while many students rejected technical engineering identities or adopted identities other than engineer, students still had to contend with normative standards of engineers that define concern with social inequalities as outside of the boundaries of engineering. This created frustration for students as they were compelled to justify their engineering identities and created additional barriers to developing identities as engineers engaged in issues of public welfare. One student said that she feels like concerns about social issues are regarded as "fluff," as something for "tree huggers." Another student similarly described how, when talking about humanitarian issues in engineering, "people immediately see people wearing ponchos, hugging trees, dancing around outside … I don't think that's what it's about. I think that that's my perception of the outside looking in."

Although this student was very enthusiastic about addressing social inequality and engaging with public welfare issues in engineering, he still had to defend against outside perspectives that framed such engagements as apart from engineering. These examples illustrate how students had to contend with internalized and implicit messages about what it means to be an engineer and what is included in engineering. These messages devalued or excluded public welfare from the purview of engineering work and engineering identity, making it more difficult for students engaging in deliberations about public welfare in engineering to establish identities as engineers and legitimize their work within the scope of engineering practice.

4.2 | Justifying the value of nontechnical work and relevance to engineering

Students engaged in boundary work (Lamont & Molnar, 2002) to negotiate the scope of engineering and to justify the value and relevance of nontechnical work. While many students defended the importance of public welfare concerns, their embrace of nontechnical work was often fraught and incomplete. Students still invoked normative conceptions of engineering that marginalized nontechnical knowledge and practices, including interdisciplinary knowledge and community engagement.

For example, one student expressed that engineers are not qualified to engage in surveys with communities, concluding, "I am an engineer—I don't know how to talk to people!" In another example, a student described frustration at being given writing assignments rather than technical work, exclaiming, "I am an engineer! Give me something engineer-y!" Although these students had self-selected into programs that focus on engaging with public welfare issues, the references to engineering identity as justification to exclude writing and community engagement demonstrate that many students still employed dominant, technocentric conceptions of engineering when determining the boundaries of engineering knowledge and practice.

The formation of boundaries around what is included and excluded from engineering was not straightforward, and students often engaged in conflicting practices that involved both taking up and also rejecting normative conceptions of engineering. For example, during one interview, a student emphasized the importance of deep engagement with the cultural context in which engineering projects take place. However, later in the same interview, the student expressed the following seemingly contradictory statement:

> If somebody is designing the building that we are in, I don't really care if they know about the historical context … I care that they're really, really good at designing structurally sound buildings.

This kind of negotiation reflected the tensions and unsettled boundaries between what students considered to be inside or outside the scope of their responsibilities and practices as engineers.

To justify the legitimacy of engaging with public welfare issues, some students described integrating social context into engineering as particularly "complex," or "more challenging" than traditional engineering, using difficulty—a quality that is normatively valued in engineering—to validate public engagement. However, for one student, the perception that the work she was doing was not "as technical" or "hard" as other fields, along with the prevalence of women in her program, created an additional struggle to assert legitimacy. As she put it:

> Sometimes when I see myself in these fields that are predominantly women, I'm like, "Oh, I'm just following the stereotypes. I'm not doing something that's as technical, or hard, so it's not as respected or prestigious." I think I struggle internally with that.

Although this student also expressed passion and enjoyment for her program, she also had to cope with the additional burden of gendered messages that she perceived to devalue the legitimacy of her work, both because of its social focus and because of the greater inclusion of women in her field. This student's statement also highlights how the technical/social dualism in engineering is also a gendered dualism in which "the social" is feminized and devalued (Faulkner, 2000, 2007).

Students also expressed frustration when confronting messages that framed engagement with public welfare issues as external to what they heard referred to as "real" engineering practice. One student described her irritation when hearing that engineering work in her program was discounted as "community work," "not engineering," and "not real science." Another student expressed that he felt that public welfare issues get "put in a box of social work" rather than being included as an integral part of engineering practice. Similarly, one student described how, when she first arrived at the engineering college and told her engineering peers that she wanted to "have a good time and figure out how to make a difference," they quickly discouraged her. She soon came to realize that many of her peers were there "to get a good paying job" rather than make a positive social impact.

One of the most striking examples of how students had to contend with actions that delegitimized their engagements with public welfare was when one student described an experience during an internship interview where, when she talked about the importance of working collaboratively with communities, she was told that this kind of work "doesn't sound like real engineering," that she was "not a real engineer," and that she "should just go be a social worker" instead. The student was given the message that if she wanted to engage with issues of public welfare, she should pursue an entirely different profession. This exchange represented a potent barrier for this student as she tried to integrate her concerns for the public good into engineering.

All of these examples represent how students grappled with messages that framed engagement with public welfare and concerns for the social context and social impacts of engineering as either marginal within engineering, or else excluded entirely. While students were often very excited and passionate about their work and the importance of knowledge about social context and social impacts of engineering, they also had to engage in additional mental and emotional labor to justify their work as "real engineering" and to establish themselves as legitimate engineers. This extra work created challenges for engaging with public welfare issues in engineering, deterring students from such practice.

4.3 | Redefining engineering expertise and integrating community knowledge into projects

A central component of both programs we studied was to teach students that to improve public welfare, they must think beyond mathematical and scientific problem-solving and consider the views and desires of the communities with whom they work. In doing so, these programs provoked a redefinition of the boundaries of engineering expertise through integrating the perspectives of non-engineers and knowledge of social context into engineering projects. However, we found the process of redefining expertise was uneven and filled with tensions, as students both adopted and resisted new ways of thinking and valuing community knowledge.

For example, during observations at events and classes as well as during interviews, students frequently expressed sentiments that problems are not just technical, and that knowledge of social context is needed to understand and address engineering problems and promote public welfare. One student described this approach to engineering as "not just the scientific solutions—it's understanding the sociological, the geological, the political, the whole overarching themes of humans in their complexities."

Students also often described their programs' emphasis on public welfare as involving epistemological shifts, such as focusing on "how to redefine problems," developing "a way of thinking," and "asking different kinds of questions." Understanding community perspectives was a central part of these programs' approaches to engineering. Classroom examples often focused on failed and detrimental projects where engineers had implemented projects without clear communication and consultation with the communities with whom they were working. Students were taught that communities had important and valuable input and should be involved in the design and creation of engineering projects. One student emphasized the importance of "co-creating" projects with communities and stated that "communities have a lot to give, and they should have design power as well." As another student put it, "I've come to learn that really, it's the engineers that are learning from the communities, not the other way around."

However, while students expressed the value of collaborating with communities, they also experienced tensions and confusions when community perspectives conflicted with their notions of engineering expertise. For example, one student described his frustration when he was interning with an earthquake resiliency project in the global south that was vandalized by local residents. For this student, there was an "obvious" need for earthquake resistant buildings in this area, and he felt frustrated that the community did not have the same point of view:

> At night the community would come in, and they trashed the [work] site—destroyed all the work, all the tools … They did not want it; they didn't think that they needed it … And my first reaction was like, "Why would you do that? That's stupid. We're here to help you."… Because for me, from the American, the Western way, the engineering way, it's common sense and it's obvious.

This student described the frustration he felt when facing conflicts between what he believed was right for the community and what the community wanted. He framed the Western "engineering way" as oppositional to community and non-Western perspectives. This opposition created external conflict with the community as well as internal conflict for the student as he wrestled with understanding a different perspective. Furthermore, while "common sense" may seem natural and taken-for-granted, common sense is a culturally situated knowledge structure rather than a universalized value (Geertz, 1975). The student's understanding of the "engineering way" as "common sense" and "obvious" highlights how engineering expertise was hierarchically naturalized in opposition to community viewpoints.

In another example, a student expressed frustration when learning about different belief systems, such as Indigenous beliefs, that challenged the universal authority of Western science. At first, the student emphasized the importance of

Indigenous perspectives, explaining: “I think the crux of the issue is that by not acknowledging Indigenous beliefs, we are kind of looking down on them.” The student continued on to say:

> That's something that I still haven't come to terms with. Because to me … science is my truth. These are my guiding principles. And so, I get really angry in class and I have to step back and be like, “Okay, this is what they believe.”… I have to be able to work with these kinds of people, you know?

Here, the student actively expressed a desire to learn about Indigenous perspectives and integrate these perspectives when working with Indigenous communities. However, the student also described frustration when trying to integrate these viewpoints into engineering because these perspectives challenged Western scientific knowledge. The student struggled to reconcile the differences between community knowledge and the student's understanding of engineering science. This presented another challenge to integrating cultural knowledge and social context into engineering practice.

These examples illustrate how, while students recognized the importance of integrating community knowledge and perspectives into engineering to better understand and serve the needs of the public, they also encountered difficulties and confusions when their values and knowledge conflicted with those of the community. Students often expressed frustration or doubt as to how to approach problems in which their conceptions of Western scientific methods and engineering knowledge—or the “engineering way”—differed from community desires. Some students found dominant conceptions of engineering knowledge and practice as being incompatible with full integration of community knowledge. This limited the extent to which students were able to consider and incorporate the needs and desires of the communities that they serve, representing another barrier to engagement with public welfare in engineering.

4.4 | Addressing ambiguous questions and ethics

Another area of conflict for students was how to approach ambiguous questions and ethical dilemmas. Students in the programs we studied learned about the ethical dilemmas and social consequences of their work. However, because many ethical questions regarding the social impacts of engineering do not have well-defined answers, addressing ethical dilemmas and ambiguous questions also challenged engineering's typical focus on measurable constraints and clearly identifiable solutions (Baillie & Armstrong, 2013; El-Zein & Hedemann, 2016; Godfrey & Parker, 2010; Riley, 2008). At other times, students expressed the view that ethical questions seemed overly simplified, which also detracted from their value and relevance.

The programs that we studied emphasized that working with communities on projects may involve conflicting perspectives about what kind of project is needed, the potential benefits and harms of the project, and differing values between the engineers and community members. These differences created a conflict for many students, who expressed that they just wanted to know “what to do,” “what's the solution” and “how do we fix this.” As one student explained, emphasizing the hierarchal value of practical knowledge in engineering education, “if engineers don't come out of class feeling like we learned how to do something new, then it feels not as useful.” By referencing engineering identity to explain why students do not find knowledge as valuable unless it has clear applications, this comment demonstrates how conceptions of engineering as applied problem-solving curtail the inclusion of broader, reflective knowledge and ethical considerations.

When asked about different ethical dilemmas that they have either experienced in their work or talked about in class, students frequently described feeling frustrated that, as one student noted, “there's never just an answer that works for every situation.” This sentiment was shared by another student who expressed with a tone of frustration and disengagement, “there is no answer! How long can you talk about it? It is like mental gymnastics to try to get your brain around some of these concepts.” This student continued to explain that many ethical dilemmas are “philosophical questions that a bunch of engineers are never going to talk about.” The student dismissed big-picture ethical questions as something more in the realm of philosophy rather than engineering, excluding these issues from the scope of engineering expertise.

Other students also expressed that more ambiguous questions and ethical dilemmas were particularly difficult for engineers because of the way that they have been trained to address problems. As one student explained:

> It is a very tiring process. Because you're constantly questioning yourself. Is this the right way to look at it? And there's no "yes" or "no" answer. I think as engineers, we love to hear "yes" or "no." It's either right or it's wrong.

This student referenced normative conceptions of engineers as wanting clear-cut "yes" or "no" answers. This concept of engineering problem-solving may be incompatible with the more complex ethical problems and dilemmas that do not have clear "right" or "wrong" answers.

This concept was echoed by another student who emphasized how engineers have an affinity for problem-solving that clearly results in right answers:

> A lot of engineers will tell you this: when you get into a math problem and you start to figure it out, or you think you can figure it out, it's almost like an addiction … it's this weird high you get from getting a question right.

The strong preference given to approaches to problem-solving that have right or wrong answers marginalizes engagement with broader open-ended questions and ethical dilemmas. When encountering complex ethical and ambiguous questions, many students felt frustrated that there was not a clear answer, and at times this led to disengagement with these topics of discussion.

At the same time, students also expressed that the Engineering Code of Ethics (NSPE, 2018b) often seemed over-simplified and that classroom activities centered around these ethical principles frequently felt irrelevant, especially when students already felt overburdened with large workloads. Voicing his frustrations about the way that the Code of Ethics is taught in the classroom, one student explained: "It is of no importance. Which makes you angry. You're like, 'I'm so busy, I have so much math to do right now!'" This student's statement also highlights the way in which mathematical work is privileged over ethical considerations in engineering education. Another student also voiced frustration at the simplicity of the Code of Ethics, explaining that it is summed up as: "Be safe. Don't kill people with your designs." When asked about ethical responsibilities among engineers, several students emphasized the primacy of making sure that buildings don't collapse and that their designs are safe. These represent the kinds of worst-case scenarios that Kline calls "disaster ethics" (Kline, 2001, p. 14) where "the outcome often determines the analysis" (Kline, 2010, p. 19) as opposed to more nuanced ethical questions such as the impacts of technology on society (Herkert, 2000) or the ways in which institutional structures may contribute to the invisibility of ethical concerns (Lynch & Kline, 2000).

These students' statements illustrate the complex interplay of challenges encountered when addressing ethics in engineering. On one hand, broad ethical issues that involve competing value systems or ambiguous approaches were often seen as too open-ended for the engineers to address. These more complex ethical problems contrasted with dominant, reductive approaches to engineering problem-solving, making them more difficult for students to learn and integrate into engineering knowledge. Yet at the same time, when ethical issues were framed in more simplified terms such as the importance of whistleblowing, not taking bribes, or making sure designs are safe, these issues were seen as self-evident and obvious. The ease of answering these kinds of ethical questions contrasted with the value of rigor and difficulty in engineering, making these questions seem less relevant and important to engineering students. The emphasis in engineering on clearly definable solutions as well as the value placed upon technical knowledge and difficulty created barriers to students' engagement with complex ethical questions in engineering that have significant implications for public welfare.

5 | DISCUSSION

5.1 | Summary of findings

Despite prevalent notions of engineering as an apolitical scientific practice, engineering is deeply embedded in the social structures and inequalities of society. Increasing explicit engagement with issues of public welfare in engineering education is necessary for increasing engineers' ability to take responsibility for the social impacts of technology and to ethically serve society to their fullest potential. Drawing upon student experiences in two engineering programs that emphasize consideration of public welfare issues, our study explored the barriers to increasing engagement with public welfare in engineering education. Previous research has demonstrated how engineering education has produced dominant visions of what counts as "real" engineering. The hierarchical dualisms between the technical and the social have created a culture in engineering that marginalizes consideration of public welfare concerns (Cech, 2014).

We examined the challenges that students encountered when considering public welfare issues to understand the barriers to public welfare engagement in engineering. Efforts to engage engineering students with public welfare issues challenged dominant conceptions of engineering identity, knowledge, and practice, by emphasizing the importance of social context, community perspectives, and the complex and uneven social impacts of engineering on society. We found that such efforts forced students to contend with conflicting norms about engineering, creating frustration and confusion for students and inhibiting their capacity to engage with public welfare issues.

Students employed varying strategies to justify public welfare engagement in engineering and revise the boundaries of engineering identity, knowledge, and practice. These included complex processes of rejecting, accepting, and resisting normative, technocentric conceptions of engineering. We identified the particular areas in which students experienced difficulties as (a) defining and defending their identities as engineers; (b) justifying the value of non-technical work and relevance to engineering; (c) redefining engineering expertise and integrating community knowledge into projects; and (d) addressing ambiguous questions and ethics. Feeling frustrated is not necessarily detrimental; however, without significant support to process that frustration, students may be discouraged from engaging in these kinds of conversations and practices. The marginalization of public welfare considerations has potent consequences for students as they seek future employment, for faculty as they seek professional tenure, and for programs as they seek to accumulate institutional resources and support. The relevance and value of public welfare engagement in engineering matters greatly for the advancement and continuation of these educational practices, the professional development of engineers, and the impacts on society as a whole.

5.2 | Strategies for supporting public welfare engagement

Despite these difficulties in integrating public welfare issues into engineering education, we also found that many students expressed that pursuing public welfare engagement provided an impetus for them to continue within the engineering field. This finding lends support to Rulifson and Bielefeldt's (2017) analysis of links between social responsibility and student retention in engineering. Furthermore, we also identified key mechanisms through which students were better able to establish commitments to public welfare that are relevant to engineering programs, broadly.

Many students discussed how it was vital to develop social networks and faculty support to both cope with frustrations and explore questions about public welfare engagement in more depth. Students also stressed the importance of social groups (both program-sponsored social events as well as informal social groups) as central sites where they could process their frustrations, share interests and excitement, and cultivate a sense of belonging within engineering.

Moreover, larger networks of support were not the only component that strengthened student engagement with public welfare. Students also spoke about the importance of faculty relationships such as conversations with faculty that helped to spur their interest and retain engagement with public welfare concerns in engineering, the role of faculty in connecting students with research and job opportunities, and the importance of faculty in establishing broader social support through advising groups. This indicates that even in programs that lack a large emphasis on public welfare engagement, the support of individual faculty can still play a significant role in increasing students' involvement with public welfare concerns.

Additionally, although many students took classes that were *either* focused on technical learning *or* social context and impacts of engineering, many students reported that when classes integrated scientific, technical skill-building with learning on social context and impacts, these classes felt increasingly relevant and engaging. As one student explained, "you learn equations, and how to model this contaminant, but then you also learn about what social justice means." However, one student explained that because many classes are not integrated, public welfare issues were "almost like an afterthought, or something that you stick on the side." In support of positions advocated for by researchers and educators such as Leydens and Lucena (2018) and Stevens (in Adams et al., 2011), integrating social and technical classes may help resolve tensions between the competing values of the "social" and the "technical" as students may come to understand engineering as sociotechnical. Further, this sociotechnical approach would likely help to counter the "culture of disengagement" in engineering identified by Cech (2014), by intrinsically linking considerations of social context and public welfare impacts into engineering education and practice.

In sum, our research demonstrates that a significant barrier to increasing engagement with public welfare in engineering is the set of messages, actions, and structures that devalue and delegitimize nontechnical knowledge and practices; yet, there are important steps that programs and faculty can take to increase public welfare engagement. Programs can more fully institutionalize engagement with public welfare issues in engineering education through increasing funding and resources for such efforts and honoring faculty and student involvement in this work. Programs and faculty can address the four types of challenges that we identified in this article by supporting students in developing engineering identities that include public welfare concerns, honoring the value of nontechnical work, broadening engineering expertise in ways that include multiple epistemological perspectives, and integrating discussions about complex ethical concerns throughout the curricula. Engineering educators can centralize questions about social context and social inequalities into their classroom activities; can introduce a variety of epistemological methods in engineering, highlighting strengths, limitations, and assumptions of each approach (Adams et al., 2011); and can integrate some of the substantial body of literature in engineering education addressing the importance of sociotechnical approaches, some of which have been explored in this article (Cech, 2014; Leydens & Lucena, 2018; Riley, 2008). Additionally, educators can expose students to public welfare issues early in their engineering education to more fully institutionalize engagement with such issues among engineers. According to one student, this shift would broaden students' initial conceptions of engineering and prevent students from being "indoctrinated into: 'this is what an engineer is,' as opposed to: 'this is what an engineer could be.'"

5.3 | Future research directions

This study examined the experiences of students at two engineering programs to illustrate challenges to increasing students' engagement with public welfare concerns. Since the majority of the students we interviewed were enrolled in civil or environmental engineering degrees, one important direction for new research is to explore how challenges may be different for students in other engineering subfields, such as electrical, chemical, or aerospace engineering, as well as how experiences may differ among undergraduate, masters, and PhD students. In addition, further research could explore specific comparisons between particular learning environments and institutional contexts (e.g., liberal arts colleges or community colleges, colleges with low-income or more diverse student populations) and how other aspects of student identity (e.g., gender, race, nationality, and economic status) impact students' experiences and how they understand their roles and responsibilities as engineers. Furthermore, since many of the barriers to public welfare engagement invoked feelings of frustration for students, it would also be valuable to further explore the role of emotions and emotional support in assisting public welfare engagement.

Future research could focus on how programs that emphasize engagement with public welfare issues influence diversity in engineering and how race, gender, and economic status affect challenges to increasing the value of public engagement in engineering. For example, Faulkner (2000, 2007) has theorized that increasing an emphasis on the heterogeneous, sociotechnical aspects of engineering will improve gender diversity. Litchfield and Javernick-Will's (2015) study of Engineers without Borders (EWB) students also found that about half of EWB students were women, much higher than the 20–25% inclusion of women in engineering as a whole (NCSES, 2019). Additional research could explore how shifts in engineering educational culture to include more explicit engagement with public welfare issues may increase gender diversity in engineering as well as other aspects of diversity such as economic status, sexual orientation, racial identity, and ethnicity.

6 | CONCLUSION

Engineers have a great capacity to impact society, and training engineers to understand and take responsibility for the social implications of their work is a crucial challenge of engineering education today. Due to deeply ingrained cultural norms and values that obscure the importance and relevance of the social impacts of engineering, training engineers to integrate knowledge of social responsibility and engagement with public welfare is particularly challenging. If programs are to succeed in preparing engineers to fulfill their professional duty and ethical obligation to serve society, then more attention must be given to the interactive processes through which student learning and public welfare engagement take place. Understanding student perspectives and difficulties is essential to supporting student learning and success. This support involves not only teaching new material in the classroom but also challenging the explicit and implicit replication of technocentric engineering norms and providing support for students to increase community belonging as they develop their identities as professional engineers. Engineers play a central role in establishing the social structures of societies. What kind of role they play and what future society will look like vitally depend on approaches in engineering education today.

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ENDNOTE

[1]Two masters students were interviewed twice at their request because they were interested in sharing about how their viewpoints had changed over time.

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APPENDIX A: INTERVIEW RESPONDENTS

Name	Institution	Career	Field	Gender
Student 1	A	Undergraduate	Civil	M
Student 2	A	Master's	Civil	M
Student 3	A	Master's	Civil	M
Student 4	A	Master's	Civil	W
Student 5	A	Master's	Civil	M
Student 6	A	Master's	Environmental	M
Student 7	A	Master's	Environmental	W
Student 8	A	Master's	Environmental	W
Student 9	A	Master's	Environmental	W
Student 10	A	Master's	Environmental	W
Student 11	A	PhD	Civil	M
Student 12	A	PhD	Civil	M
Student 13	A	PhD	Civil	M
Student 14	A	PhD	Civil	W
Student 15	A	PhD	Civil	W
Student 16	A	PhD	Civil	M
Student 17	A	PhD	Environmental	W
Student 18	A	PhD	Environmental	W
Student 19	A	PhD	Environmental	M
Student 20	B	Undergraduate	Mechanical	M

Name	Institution	Career	Field	Gender
Student 21	B	Undergraduate	Chemical	W
Student 22	B	Undergraduate	Civil	W
Student 23	B	Undergraduate	Environmental	W
Student 24	B	Undergraduate	Environmental	W

APPENDIX B: SUMMARY OF INTERVIEW PROTOCOL AND CORE INTERVIEW TOPICS

We recruited the majority of interview respondents through personal contact during observations of program events. We also employed snowball sampling, asking interviewees to suggest other people within the program whom we could contact for interviews. Following our Institutional Review Board (IRB) protocol, when recruiting participants for the interviews, we outlined the broad goals of our research and emphasized that participation in the research is voluntary and that there was no payment for participation. We conducted semi-structured interviews, focusing on core topics such as:

- The student's motivation for joining their engineering program.
- Ethical dilemmas that they have encountered in the classroom and in the field.
- What is important to consider when working with a community on engineering projects.
- How classroom activities or fieldwork experiences have changed their perspectives on engineering.
- What is the role of engineers in contributing to social welfare and reducing social inequalities.
- What it means to be a responsible engineer.
- What are the capacities and limitations of engineers in supporting community needs.

We also asked interview participants if there were any questions that we did not ask or topics that they feel are important to share about with us that are relevant to the research goals. This semi-structured format allowed for a collaborative discussion during the interview and in-depth exploration of novel topics and recurrent themes.

APPENDIX C: FLOWCHART OF CODING PROCESS [Color figure can be viewed at wileyonlinelibrary.com]