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PAPER

Investigating Impacts of Socially Engaged Engineering and Design Case Studies in Undergraduate Engineering Courses

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ABSTRACT

Engineering practice needs a sociotechnical skillset that integrates deep technical knowledge with the capacity to navigate complex social, contextual, and environmental dimensions. To address the traditional technocentric bias of undergraduate engineering curricula, the University of Michigan's Center for Socially Engaged Engineering and Design (C-SED) developed and implemented a series of microhistorical "SEED" case studies. This study utilized a survey of 333 engineering students to investigate participant perceptions regarding the benefits, drawbacks, and skills developed through these educational experiences. Quantitative and qualitative findings demonstrate that a substantial majority of students recognized the real-world relevance of the material, reporting enhanced capabilities in identifying the social impacts of engineering decisions, mapping stakeholder perspectives, and evaluating system trade-offs. While the study revealed a small degree of resistance from students grappling with entrenched expectations of what constitutes "legitimate" engineering knowledge, the overall results demonstrate that integrated, well-supported case studies offer an effective curricular intervention to foster socially engaged engineering competencies across various disciplines.

KEYWORDS

case studies, sociotechnical engineering, undergraduate curriculum

1 INTRODUCTION

Modern engineering work requires a broad array of skills and knowledge, including a deep technical understanding and the ability to account for the ways in which engineering problems and solutions are shaped by and impact the broader societal and environmental context in which engineering work is situated [1]–[3]. While some engineering problems, such as those related to healthcare or infrastructure, have more obvious societal and environmental connections than others,

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dimensions such as human perspectives, team decision-making dynamics, materials sourcing, and energy usage are key considerations across engineering disciplines and industries. The understanding and practices necessary to identify and incorporate details of social, contextual, and environmental dimensions of engineering work in a manner that is responsive to potential tradeoffs and the relative position and power of interested and impacted parties, referred to in this paper as socially engaged engineering skills and knowledge, are increasingly recognized as key outcomes of engineering training. The Accreditation Board for Engineering and Technology (ABET) [4] includes the following socially engaged skills as student outcomes for accreditation:

> *an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors,* and
>
> *an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts*.

While socially engaged engineering skills are now commonly recognized as important, integrating these skills into the engineering curriculum requires countering long-established norms of a technocentric approach to engineering training. A technocentric framing of engineering work, long-dominant in the United States, positions social considerations as distinct from and beyond the rightful purview of engineering practice [5]–[8]. Prior scholarship suggests that technocentric engineering training can prevent engineers from engaging with the societal impacts of their work and mask the ways in which engineering work is shaped by societal forces [9]; technocentric engineering training has even been linked to students' disengagement with social welfare concerns over the course of their degree program [10]. Compared to technical skills and knowledge, socially engaged engineering skills are typically not well-integrated into the engineering curriculum. Often, when these socially engaged skills are taught, it is in the context of a single course or course session [11]–[14]. Shifting long-held technocentric beliefs about engineering work thus requires strategies for integrating socially engaged engineering skills and knowledge throughout the engineering curriculum [15], [16].

Identifying effective approaches to integrating socially engaged skills into engineering curricula requires, in part, an understanding of how they contribute to student learning and how they are received by students, whose expectations of what engineering work constitutes may already be shaped by pervasive technocentric messages. The present study explores one approach to integrating socially engaged engineering skills throughout an engineering curriculum: Socially Engaged Engineering and Design (SEED) case studies, developed and implemented by the University of Michigan's Center for Socially Engaged Engineering and Design (C-SED). We drew on data from a survey of 333 engineering students, which included a series of Likert-type and open-response items, to explore students' perceptions of the benefits and drawbacks of the case studies implemented in their classes and the skills and knowledge they reported developing through the case study lessons. Our findings will inform efforts to refine the SEED case study approach and provide transferable insights into students' priorities and learning associated with socially engaged engineering training that can be leveraged by other scholars and educators engaged

in efforts to ensure engineers are well-prepared for the sociotechnical realities of modern engineering work.

1.1 Background

1.2 Student conceptions of engineering as a sociotechnical discipline

Research suggests that many engineering students hold relatively narrow, technocentric conceptions of engineering that emphasize technical knowledge and problem solving over broader contextual, social, and human dimensions of engineering practice [9], [10], [17]. These conceptions are evident in how students describe the nature of engineering work. For example, one study of first-year engineering students found that participants most commonly described engineering as applied science, artifact design, and technical problem solving, while many characteristics of engineering practice emphasized in the literature—including multidisciplinary collaboration, professional judgment, communication, and broader societal impacts—were absent or only weakly represented in students' descriptions [18]. In another study, interviews with engineering students revealed that many struggled to justify the relevance of broader social considerations to engineering practice, often positioning nontechnical work as peripheral to engineering expertise and expressing uncertainty about how community knowledge or public welfare fit within engineering work [9]. A study of upper-level engineering students provides another example of how students have interpreted the social dimensions of engineering in limited ways; participants in this study who described engineering as a social discipline primarily associated this idea with teamwork and interpersonal communication rather than engagement with people outside of the project team or consideration of the societal impacts of engineering decisions [19]. These conceptions also appear in students' approaches to engineering design. One study found considerable variation in the extent to which first-year engineering students incorporated contextual considerations when scoping engineering design problems, suggesting that while some students readily attended to contextual factors, others gave them comparatively little attention [20].

Students' conceptions of engineering are also reflected in how they describe what it means to be an engineer. For example, one study found that students' understandings of sociotechnical thinking were closely connected to how they conceptualized engineering and their place within it, with several participants expressing uncertainty about whether the incorporation of broader societal considerations was consistent with what it meant to be an engineer [21]. Similarly, research on liminal engineering identities found that some students questioned whether they could legitimately identify as engineers until they possessed the kinds of technical knowledge and experiences they associated with the profession [22].

1.3 Prior efforts to integrate socially engaged content into engineering education

Over the past several decades, engineering educators have increasingly sought to incorporate socially engaged engineering skills and knowledge into

undergraduate curricula. These efforts have addressed topics including human perspectives, public welfare, ethics, sustainability, social responsibility, and the broader social, environmental, and organizational contexts in which engineering work occurs [23], [24]. Although these efforts differ in their specific emphases and learning objectives, they share a broader goal of helping students understand engineering as a sociotechnical endeavor in which technical decisions both shape and are shaped by people, communities, organizations, and the environment.

Socially engaged engineering skills and knowledge have often been addressed through stand-alone courses or instructional units focused on topics such as engineering ethics, sustainability, engineering and society, or social responsibility rather than being integrated throughout engineering curricula [11]–[14], [25]. More recently, scholars have argued that preparing engineers for the sociotechnical realities of practice requires moving beyond isolated instructional experiences toward integrating social considerations throughout the engineering curriculum [23], [24].

National studies of engineering curricula suggest that socially engaged engineering skills and knowledge are most commonly incorporated into introductory and capstone engineering design courses [26]–[28]. For example, some design courses have incorporated structured engagement with people throughout a design process, using approaches such as client-provider relationships and facilitated interactions to help students elicit diverse perspectives, negotiate design requirements, and incorporate those perspectives into engineering decisions [29], [30]. Other design courses have situated engineering projects within authentic community contexts, asking students to address community-identified needs through human-centered design processes and sustained partnerships with community organizations, often emphasizing sustainability, social justice, and other broader societal considerations as integral components of engineering design [31]–[33].

The Center for Socially Engaged Engineering and Design developed a series of modular "learning blocks" that have been implemented in multiple engineering design courses, including first-year and senior design courses, to support the development of specific socially engaged engineering and design skills [34], [35]. Designed as flexible instructional modules, the learning blocks can be integrated into existing design courses without requiring extensive course redesign. Learning blocks have been developed to scaffold skills such as problem definition, engineering design interviewing, observation, and designer positionality [35]–[38]. Studies of the design interviewing learning block found that students improved their ability to elicit and interpret people-centered information to inform engineering decisions [35], [38], while instructors reported that the modular format was flexible to implement within a range of engineering design courses [34].

Researchers have also explored a variety of approaches for integrating socially engaged engineering skills and knowledge into engineering science courses. For example, Lucena and Leydens [39] proposed a pedagogical framework for integrating societal considerations into engineering science courses and illustrated its application in feedback control systems, signal systems, thermodynamics, and chemical process engineering. Similarly, Reddy and colleagues [40] described modules that introduced social relevance and global context into a required heat transfer course, Lord, Przestrzelski, and Reddy [41] developed instructional modules examining topics such as conflict minerals, solar energy, and electronics recycling within an introductory circuits course, and Gelles and Lord [42] incorporated sociotechnical modules into an introductory materials science course. Their findings suggested that students developed greater awareness of social and environmental dimensions of

engineering while also expressing a need to move beyond surface-level awareness to better understand how engineering decisions directly affect people and communities. Collectively, this body of work demonstrates growing interest in integrating societal dimensions across engineering curricula while highlighting the continued need for approaches that can be implemented across a broad range of engineering courses and disciplines.

1.4 Case studies

Case studies provide one mechanism for integrating socially engaged engineering skills and knowledge into engineering courses by situating technical concepts within broader social, environmental, and organizational contexts. Unlike decontextualized technical exercises, case studies present students with complex scenarios that require consideration of multiple factors, including human perspectives, competing priorities, and the consequences of engineering decisions [13], [43]–[45]. In engineering education, case studies have been used to support students' development of systems-level thinking and their ability to examine the interconnected technical and societal dimensions of engineering problems [46], [47].

Case studies have been used to connect technical engineering concepts with socially engaged engineering skills and knowledge by providing students with opportunities to examine engineering problems within their broader contexts. For example, whole-systems design case studies have been used in first-year engineering courses to strengthen students' consideration of concepts such as integrative design, design for multiple benefits, and system-level optimization [46]. A sociotechnical case study examining a controversial wind energy project in Hawaii found that students considered the roles of different groups and social factors in engineering projects while also revealing challenges in moving beyond technical-versus-social framings of engineering decisions [48]. Nortz and colleagues [49] described a sociotechnical module in an introductory circuits course that connected capacitors with the social issue of conflict minerals. Similarly, course-integrated case studies focused on energy and society in thermodynamics, circuits, and statics and dynamics courses were developed to support students' development of sociotechnical judgment [50]. Infrastructure-focused case studies examining the impacts of extreme storms have also been used in introductory civil engineering education to help students understand engineering practice within broader societal contexts [51].

1.5 Student responses to socially engaged engineering content in engineering courses

Students frequently report wanting greater connections between engineering coursework and real-world practice, reflecting a desire to understand how technical concepts apply beyond the classroom. Foundational work by Seymour and Hewitt [52] found that students who left STEM fields often expressed frustration with coursework that emphasized abstract concepts without clear connections to meaningful applications or professional practice. More than two decades later, follow-up research similarly found that students valued instructional approaches that helped them understand the relevance and application of what they were learning [53].

Similarly, engineering students have identified opportunities to engage with authentic engineering problems and understand the relevance of their coursework as important aspects of their educational experiences [54]. In a study of a basic electric circuits course, Gero, Stav-Satuby, and Yamin [55] found that incorporating real-world examples into course content increased students' motivation and perceptions of relevance.

Research examining students' responses to socially engaged engineering content has generally found that students value opportunities to connect technical knowledge with broader societal contexts. Across a range of instructional approaches, students have described this content as relevant to engineering practice and helpful for understanding the people and contexts affected by engineering decisions. For example, students who completed sociotechnical modules in an introductory materials science course reported greater awareness of the social and environmental dimensions of engineering while also recognizing the need for deeper understanding of how engineering decisions affect people and communities [42]. Similarly, students in an introductory circuits course viewed a module connecting capacitors and conflict minerals as valuable and relevant, with many reporting that it helped them better understand real-world engineering practice [49]. Students have also described sociotechnical aspects of engineering courses as among the most memorable components of their learning, particularly when instruction emphasized who is affected by engineering and the kinds of engineers students hoped to become [56].

Beyond viewing this content positively, students have also described changes in how they think about engineering practice. Across multiple studies, students reported greater attention to the people affected by engineering decisions, increased consideration of social factors alongside technical ones, and greater recognition of the complexity of engineering practice [36], [48], [57]. Some students also reflected on issues such as bias, inequity, and the limitations of purely technical solutions [57], while others described learning to recognize their own subjectivity, seek multiple perspectives, and engage with community partners throughout the engineering design process [36]. One study found that participants viewed the sociotechnical emphasis as affirming of both their engineering interests and their place within the profession [58].

Although students often respond positively to socially engaged engineering content, studies also describe tensions that arise as students reconcile these ideas with dominant technocentric conceptions of engineering. Niles and colleagues [9] found that students sometimes experienced frustration and uncertainty as they grappled with questions about whether public welfare, community knowledge, and nontechnical work belonged within engineering, leading some to resist expanding traditional definitions of engineering expertise. Similarly, while students in Nortz et al.'s [49] study valued the sociotechnical module overall, some expressed concern about adding new material to an already content-heavy engineering course. These findings suggest that students often recognize the value of socially engaged engineering content while also navigating tensions created by longstanding expectations about what counts as engineering knowledge and practice.

2 METHODS

This study explored student perceptions of the use of case studies in various engineering courses, looking specifically at cases designed to support students'

awareness and development of socially engaged skills and knowledge developed by C-SED at the University of Michigan. As the use of these case studies began to expand throughout the College of Engineering, we sought to understand how students across courses and departments experienced the case studies and how the cases supported student learning. We drew on both Likert-type scale data and open-ended responses from a survey of 333 primarily undergraduate students who completed case studies in their courses to explore the following questions:

- What engineering skills and knowledge do students report the case studies helped them to develop?
- What do students perceive to be the benefits and drawbacks of integrating socially engaged case studies in their course(s)?

2.1 Positionality

The first author has a background in higher education with a focus on engineering contexts, and the second author has a background in both engineering and engineering education. Both authors are White women. While not directly engaged in the writing or delivery of the SEED case studies, both authors are affiliated with C-SED—primarily focused on program assessment and related research initiatives. The second author is also a C-SED co-founder. Our shared commitment to developing and deploying effective strategies for preparing engineers with the socially engaged skills and knowledge to more fully engage with engineering as a sociotechnical discipline both motivates our work with C-SED and the focus of the present study. While our interest in broadening students' engineering training to include socially engaged topics led us to hope that interventions such as the SEED cases studies would be well-received by students and support their learning, it also led us to be sensitive to potential barriers or student misconceptions about engineering as a sociotechnical endeavor. Recognizing our own orientations, we aimed to be particularly attentive to student perspectives that were unfavorable or more uncertain about the case studies or their relevance to engineering throughout our analysis process. In addition, we reiterated in our survey recruitment messaging and the survey itself that we valued divergent perspectives and feedback about the SEED case content and their integration into courses.

2.2 Content and Implementation Context of SEED Case Studies

The Center for Socially Engaged Engineering and Design, founded in 2015, works to support engineers in developing the skills and knowledge necessary to actively account for and integrate societal, contextual, and technical dimensions throughout a problem-solving process. C-SED has developed an extensive collection of educational resources that are designed to be tailored to the specific objectives and content of a wide range of course types, engineering fields, and academic levels. SEED case studies are among these educational resources, with around 30 different cases currently offered that highlight various dimensions of socially engaged engineering practice and the societal impacts on and of engineering work. SEED case studies have been developed and implemented in partnership with engineering faculty, identifying case topics aligned with the focus of a particular course. The case studies are written as microhistories, leveraging real examples from engineering practice

and the history of technology and society. C-SED offers flexible delivery options for case studies and other educational resources, including asynchronous online learning modules, class sessions taught in person or virtually by a team of trained graduate facilitators, or working with instructors to support their independent facilitation of a session. The majority of the sessions described in the present study were led by graduate facilitators, in consultation with instructor partners to tailor sessions for their particular course focus. Students in the present study participated in one or more case studies on the 16 topics shown in Table 1. The case studies were integrated into a wide range of courses across all four years of undergraduate coursework, with one course cross-listed as a graduate-level course. Course types included introductory, capstone, and other types of design-focused courses, non-design technical courses with an emphasis on engineering science topics, engineering communication courses, and special topics courses that focused on topics like engineering culture or professional skills and environments.

Table 1. Summary of case study topics and course types in which they were implemented

Case Study	Brief Description of the Case Study Focus	Course Type(s) Implemented
Short-Term Home Rental Reservation Systems	The unintended consequences of design decisions using the example of a short-term rental company's early decisions around their reservation system, how these decisions led to problems with racial discrimination in the booking process, and the subsequent actions the company took to address these problems	Design-focused courses, Engineering communications course
Pulse Oximeters	Reduced accuracy of pulse oximeters in measuring blood oxygen levels for people with darker complexions, the limitations of this technology in clinical settings, the decision to adopt and continue to rely on the technology despite these limitations, and the role of stakeholder priorities and contextual factors in engineering decisions	Design-focused course
Hurricane Katrina	Socioeconomic and racial disparities in the impacts of 2005 Hurricane Katrina in New Orleans explore the suffering that resulted from engineering failures, the degree to which underlying issues were addressed in the post-2005 response, and what accountability means in engineering decision-making	Non-design technical courses
Satellite Internet	Low-orbit satellites have been marketed as a way to address a global divide in high-speed internet access but are costly, and the scale needed for global coverage raises questions about space collisions and the loss of the night sky; maps stakeholders for this technology to analyze their varied influence and interests in decision-making	Non-design technical courses
Wind Energy Development in Hawaii	State of Hawaii's plans for a wind energy project located on Molokai and Lanai to provide clean energy to Oahu that was ultimately stalled after resident pushback and challenges in negotiations between major stakeholders; explore tradeoffs in sustainable energy solutions, including the need for clean energy at scale and energy sovereignty of local communities	Non-design technical course
COVID-19 Diagnostics	Design of at-home COVID-19 diagnostic tools and how various factors such as ability, age, and socioeconomic status relate to accessibility of such tools and how tradeoffs in their design and use impact stakeholder groups	Design-focused course
PVC Blood Bags	Development and use of single-use PVC blood bags plasticized with DEHP and their ubiquity despite decades of questions about safety, explore potential unintended consequences, tradeoffs for stakeholders across lifespan, and frameworks engineers use to evaluate materials	Design-focused course
Urban Highway Redevelopment	Describes plans to convert a section of highway into a street-level boulevard in a reclamation effort that aims to address destruction of vibrant Black communities for the highway's original construction in the 1960s; Explores the societal context of old and new initiatives, analyzes benefits and harms to various stakeholder groups	Design-focused course; non-design technical course

(Continued)

Table 1. Summary of case study topics and course types in which they were implemented *(Continued)*

Case Study	Brief Description of the Case Study Focus	Course Type(s) Implemented
EV Batteries	Marketing for electric vehicles often promotes them as a step towards reducing climate change, but the material sourcing for the lithium-ion batteries used in EVs, as well as their manufacturing and disposal, can have negative impacts on communities that do not directly benefit from EV technology; it analyzes benefits and harms to stakeholders of the entire lifecycle of an EV	Non-design special topics course
Driver Assistance Technology	One automaker's development of "self-driving" vehicle technology that relies heavily on users in training the car's AI and a reliance on camera technology that has shown racial disparities in pedestrian detection; maps differences in stakeholder groups' power and interests and how they shape this technology	Design-focused course
Railroad Lubrication Systems	Development of railroad lubrication technology in the late nineteenth and early twentieth centuries, examining how race, racism, and organizational power shaped the recognition and distribution of benefits from engineering innovation	Non-design technical course
AI Ethics in Industry	The departure of an AI ethics researcher from a major technology company, exploring the role of organizational power, workplace culture, and systemic inequities in shaping engineers' experiences and the development of AI technologies	Non-design special topics course; Engineering communications course
Cosmetic Formulation and User Needs	Development of cosmetic formulations designed to meet the needs of people with a broader range of skin tones, examining how user needs, market assumptions, and bias shape product development and engineering decision-making	Non-design special topics course; design-focused course
Adaptive Gaming Controller Packaging	The co-design process used in the development of accessible packaging for an adaptive game controller for users with physical disabilities, the importance of stakeholder engagement and co-design, and additional barriers to address in the pursuit of a truly accessible solution	Design-focused course, Engineering communications course
Smart Shelves	Cashless smart shelf systems shift the point of purchase, track inventory in real time, and can target advertising and information on shelf displays based on customer demographics and data; they explore biases embedded in these designs and tradeoffs for various stakeholder groups	Design-focused course, Engineering communications course
Whiplash Protection System	An example of an automaker's redesign of a vehicle's whiplash protection system and testing strategies to address the disproportionate rate of whiplash injuries among women explores ways engineers can account for human variability in their designs and testing procedures	Non-design technical course

2.3 Participants

A total of 333 engineering students completed the survey. Participating students reported a range of social identities, engineering majors, and years in their program, as summarized in Table 2. All participants had completed at least one case study in one of their engineering courses in the past academic year.

Potential participants were identified via C-SED's records of the courses in which one or more case studies were taught and the students enrolled in those courses. Only engineering courses and students in engineering were included in survey recruitment. If a student was enrolled in more than one course in which a case study was taught in a given semester, they were only asked about the course in which the case study was taught most recently. Students were recruited via email using the Qualtrics survey platform. Our team sent recruitment emails to approximately 1100 students between Fall and Spring semesters, resulting in a 30% response rate.

Table 2. Participant information

Gender Identity*	Count
Man/Male/Masculine-Identifying	154
Woman/Female/Feminine-Identifying	124
Non-binary/Genderqueer	6
Declined to respond	49
Racial/Ethnic Identity*	**Count**
Asian/East Asian/South Asian/Chinese/Vietnamese/Indian/Kazakh/Pakistani	104
Black/African/African American	12
Caucasian/White	139
Latino/a/x/Hispanic/Puerto Rican/Mexican	31
Multiracial/Mixed Race/Biracial/Two or more identities	36
Other	31
Declined to respond	53
Year in Studies	**Count**
First-Year Undergraduate	111
Second-Year Undergraduate	69
Third-Year Undergraduate	80
Fourth-Year Undergraduate	54
Graduate student	17
Declared or Intended Major*	**Count**
Aerospace Engineering	24
Biomedical Engineering	27
Chemical Engineering	14
Civil and Environmental Engineering	28
Computer Science/Computer Engineering	56
Electrical Engineering	13
Industrial Engineering	32
Mechanical Engineering	108
Other Engineering Fields	21

Notes: *Based on open-ended student responses, the count may reflect more than one category for a student.

2.4 Survey development and data collection

The survey our team developed included a mix of close-ended Likert-type scale questions and open response questions in order to better understand students' learning and perceptions of the benefits associated with case study lessons. Survey questions related to students' perceptions of how the case studies taught in their courses contributed to their understanding or development of various socially engaged engineering skills, the extent to which they anticipated using these socially engaged engineering skills in their future work, their assessment of the benefits and quality of the case study lessons, what they learned from the case study, suggestions

for improvement, and general academic and demographic information. The full survey text is shared in Appendix A.

An initial draft of the survey was developed by the authors, informed by the goals, objectives, and design of the case study initiative. Specifically, the list of socially engaged engineering skills used in the Likert-type questions related to students' learning and future careers was adapted from a list of learning objectives that guided the development of the different case studies. Other survey questions were informed by larger project goals related to the integration of socially engaged engineering content into engineering coursework, supporting greater understanding of why and how engineers might account for social and contextual dimensions of their work, and a general aim of assessing and improving the effectiveness of the case study lessons and facilitation. After developing a draft of the survey, the authors sought feedback from other members of the case study team and revised survey content and language based on their feedback. Following these iterations, the team submitted the survey language and study plan to the University of Michigan Institutional Review Board and received an approved exempt determination prior to beginning any data collection.

One additional language consideration worth noting is our team's use of the term stakeholder in both case study framing and survey items. Scholars have raised important critiques of the term, noting its roots in colonial practices (see [59]). We chose to use the language of stakeholders in student-facing materials as a recognizable term that is leveraged in many of the engineering courses we partner with, but elsewhere in the paper we use other language such as "humans" to reflect the full range of interested and impacted parties associated with a given problem.

We piloted the survey instrument with a subset of students who had completed a case study lesson in their course, receiving approximately 20 responses. Both the survey pilot and later full survey distribution were conducted using the Qualtrics survey platform. The pilot survey implementation went smoothly, and responses indicated that the questions were generally understood by the students and effective in providing information about students' experiences and learning associated with the case studies. We made several minor edits to survey language prior to the full survey distribution. The survey took approximately 10–15 minutes to complete, and students were sent $20 virtual Mastercard Gift Cards for their participation.

2.5 Data analysis

Our analyses drew on student survey data collected across two semesters of the same academic year, including both Likert-type scale responses and open-ended questions. The Likert-type scale items included questions asking students to rate the extent to which case studies expanded their understanding of various engineering skills and knowledge, how relevant they anticipate these skills and knowledge to be in their future engineering work, and a series of questions asking students to characterize their perceptions of the case study content and facilitation. For these items, we calculated basic summary statistics and reported our findings using percentages of students who rated these items highly.

Open-ended survey items included questions about what students learned from the case studies, what they thought worked well about the cases, what they thought could be improved, and any other reactions or feedback students wanted to share. Both authors reviewed the open-ended items and, through ongoing discussion, identified emergent themes related to a) what students learned and b) what students perceived to be benefits or drawbacks of integrating the cases into their courses.

Guided by recommended approaches to thematic analysis [60], [61], we named and discussed initial themes, clarified and refined our characterization of each, and identified supporting evidence from students' responses.

2.6 Limitations

There are several limitations of the study that should be noted for how they may have shaped our study findings. First, our focus on capturing the breadth of perspectives of students who engaged in any C-SED case across the engineering curriculum does not allow for an in-depth exploration of the content, instruction, or effective course integration for any particular case study. For example, while students' comments highlight the importance of connecting case study topics to other course content, characterizing the relative effectiveness of a specific case study implementation in making these linkages evident was outside the scope of our study. Further, there are potential tradeoffs in the timing of our survey administration relative to when students completed a case study in their course. In some instances, the survey distribution occurred several months after students' experience of the case and could limit their ability to fully recall details about the case content and instruction. In contrast, the timing of surveys relative to case study lessons may not provide sufficient time for students to fully reflect on and recognize the potential relevance of case content to their future work, even in instances in which the student completed the survey several months after engaging with the case study. There are also possible patterns in which students responded to the survey, with those students who held stronger impressions of the cases—whether positive or negative—being more likely to respond or for their reported learning of various topics to reflect their overall perceptions of the cases. However, it is our hope that the provided incentive for survey completion and our relatively high (30%) response rate helped to address this potential response bias. Finally, our findings highlight a particular institutional context at a given point in time. At the time the survey was conducted, the institution was engaged in a college-wide initiative highlighting the importance of considering people-associated dimensions and impacts of engineering work.

3 RESULTS

3.1 Student perceptions of case studies' role in skill and knowledge development

Students generally perceived the case study lessons to be relevant and supportive of their development of socially engaged engineering competencies. Most students (77.4%) agreed or strongly agreed with the statement "The case study covered relevant engineering skills and knowledge." The percentage of students who agreed that the case study (or studies) completed in their courses expanded their knowledge or understanding of various engineering skills "To some extent" or "To a great extent" ranged from 66.5% to 89.2%. The engineering skills that students most frequently indicated that case studies advanced their understanding of included "Identifying social impacts of engineering decisions" (89.2%), "Describe the perspective of one or more stakeholders within and/or impacted by an engineering project" (88.9%), and "Suggest next steps, problem-solving pathways, or solution ideas that attend to diverse stakeholders" (88.9%). The skills students least frequently indicated were developed through the case studies include "Recognize and mitigate barriers to collaboration on diverse teams" (66.5%) and "Explain how your own identities, backgrounds, and experiences

shape how you approach engineering work" (73.1%), which were also the two skills most commonly indicated by students as not touched on at all in the particular case study they completed. Table 3 provides a summary of students' responses.

Table 3. Percentage of students indicating C-SED case study (or studies) expanded their knowledge of understanding to some or to a great extent

Skill/Knowledge	% of Students Reporting Cases Expanded Knowledge	# of Students Reporting the Topic Not Covered (Out of 333)
Identify social impacts of engineering decisions	89.2%	8
Describe the perspective of one or more stakeholders within and/or impacted by an engineering project	88.9%	10
Suggest next steps, problem-solving pathways, or solution ideas that attend to diverse stakeholders	88.9%	17
Describe the interplay between social, contextual, and technical aspects of engineering work	87.6%	16
Represent engineering problems from multiple different perspectives	85.8%	8
Recognize the complex interlocking systems in which engineering problems are embedded	84.6%	11
Identify ways that differences in identity, background, and power shape engineering processes and/or outcomes	83.0%	12
Analyze tradeoffs in engineering decisions that impact internal and external stakeholders in disparate ways	81.9%	15
Identify ways that bias plays out in engineering practice	79.8%	21
Weigh complex ethical considerations	77.1%	19
Explain how your own identities, backgrounds, and experiences shape how you approach engineering work	73.1%	23
Recognize and mitigate barriers to collaboration on diverse teams	66.5%	36

Notes: Scale: 1: Not at all, 2: To a small extent, 3: To some extent, 4: To a great extent, with the option to select "This topic wasn't covered" if the student thought the topic was not at all touched on in the case study they completed.

Students' open-ended responses describing what they learned in the case study provide additional information about how the case studies facilitated students' understanding of engineering skills and knowledge. Many students named a deeper understanding of the complexity and range of conditions that shape and are shaped by engineering work as a key takeaway from completing SEED case studies. Some students described the cases as providing insight into the nature of "real world" engineering problems and the potential consequences of not fully accounting for such complexity. As one student explained:

> *"I learned that lots of times, engineering problems are very complex, and trying to make everyone happy makes it even tougher. I also realized the difficulty of*

changing something once it has been built – if it wasn't built well in the first place, or people were excluded, it will cost a lot of money to change, so it is very important to get it right the first time."

Some students specifically described learning more about the ways in which contextual conditions might shape engineering decision-making and outcomes, such as the "history/social impacts of engineering designs," how "preexisting social dynamics" might shape engineering outcomes, and "the impacts that engineering decisions" might have on a particular community.

An additional case study outcome named by many students was their growing recognition of the need to account for people's varied perspectives and experiences that can shape engineering processes and outcomes. Specifically, many students reported gaining a deeper understanding of the importance of intentionally seeking out and accounting for the needs and interests of diverse stakeholders, beyond "just the creator and the user." One student stated:

"I learned some things about engineering that is not taught much in the classes, and looking at the impact of engineering on the people of the community. I learned that is important to involve the people you are engineering for, so they can see what is happening in their community and provide helpful input to the engineers"

Closely related to a broadening understanding of stakeholders, students also described learning to recognize multiple perspectives related to a particular problem and "how great an influence" one's perspective might have on their experience of or approach to an engineering problem or solution. More particularly, students frequently named learning more about the ways bias can shape engineering decision-making as a key takeaway from the cases. While not necessarily intentional, engineers' own perspectives and experiences may shape what engineers attend to in their designs, potentially perpetuating existing disparities. Reflecting on their SEED case experiences, one student explained the case helped them understand ways that "the bias of engineers played out in their designs. For instance, male engineering [sic] would design seatbelts, so they would only take into account the body structure of a male."

Students also shared the ways in which the SEED case studies contributed to their understanding of the potential impacts—both positive and negative—of engineering work. Specifically, students often described that while some projects might be intended to benefit a particular group, they may also cause harm to other people or the environment. As one student summarized, "something that really benefits one person may really hurt another." Other students described expanding how they might evaluate potential harms. Citing the example of lithium batteries, one student explained learning "effects of the lithium battery life cycle begin far beyond the actual creation of the batteries. The mining of the raw materials is far more damaging to local areas than I thought." While students named the potential negative impacts of engineering work, they also spoke in positive terms about reflecting more on the responsibilities and possibilities of engineers to benefit society. Describing their takeaways from a case, one student concluded: "This shows me in my time where it is a lot easier to do things, I can make an impact in communities I care about."

Beyond recognizing the complexities, influences, and potential consequences of engineering work, some students also described learning strategies for engineering practice that could help them develop solutions that better account for stakeholder needs, reduce potential bias, and improve effectiveness. Several noted learning about particular approaches to testing and accounting for the needs of a broader

pool of potential users. One student elaborated, explaining: "There needs to be more diversity in testing, like we need to see how different situations affect the efficacy of devices for different demographics."

Students also described learning about other processes for reducing bias and coming up with better solutions. Several students mentioned collaboration and exploring multiple perspectives and possible solutions, as illustrated by the following student comment:

> *"A problem can have many possible solutions, which is why it's important to brainstorm different ideas and collaborate with others who may have different ways of thinking. Diverse backgrounds can be very useful in this context."*

Finally, students often cited learning about topics particular to individual cases. For example, several students described learning about levels of autonomy in self-driving cars based on their experiences with the Driver Assistance Technology case or learning more about the grocery industry and related technologies in the Smart Shelves case. Students also described learning more about the history of particular communities, such as the distinct communities on Molokai and Lanai in the Hawaiian Wind Energy Project case, or of a particular person, like the inventor of railroad lubrication systems. As one student explained:

> *"I learned more about the inventor's path in life, in that he was hired as a fireman for the steam locomotives because management in the company didn't think black people could be engineers, it is there he gained experience working with and dealing with problems that his inventions would later address. We then contextualized this through the lens of stakeholders to see how that experience made him a stakeholder and how that affected his approach to things."*

As the above quote highlights, the presentation of the cases, grounded in rich detail about a particular engineering problem, was structured to help students build understandings relevant to their own engineering practice.

3.2 Student perceptions of benefits and drawbacks of case studies

Students' ratings of the relevance of the socially engaged engineering skills and knowledge emphasized in various case studies suggested that, overall, a majority of students agreed that SEED case study content helped them understand engineering work and was relevant to their future professional engineering work. Percentages of students who indicated they agreed or strongly agreed with statements about case study content relevance are shown in Table 4.

Table 4. Percentage of students who agreed with statements about case study content's relevance to engineering work

Statement	Percentage Agree or Strongly Agree
The case study contributed positively to my understanding of real engineering work	76.8%
The case study covered engineering skills and knowledge that are important for my future engineering work	75.6%

Notes: Scale: 1: Strongly disagree, 2: Disagree, 3: Neither agree nor disagree, 4: Agree, 5: Strongly agree.

The case study supported students' understanding of what it means to work as an engineer. Students noted that the activity offered insight into how engineering knowledge and identity might develop over time. One student appreciated "the applicability of the case study in our future engineering career," while another reflected on the unique opportunity to explore the personal dimensions of becoming an engineer:

> *"I think it was a good experience since I have never experienced such a session in our ME coursework in which we reflect on how personal factors can affect our success and learning as engineers."*

The skills students most frequently rated highly were those related to the complexity and impacts of engineering work, including "Represent engineering problems from multiple different perspectives" (93.7%), "Identify social impacts of engineering decisions" (93.1%), and "Describe the perspective of one or more stakeholders within and/or impacted by an engineering project (93.1%). Students less frequently indicated high anticipated relevance for several engineering skills related to accounting for the ways in which their own (76.5%) and others' (82.5%) backgrounds and identities shape engineering work and outcomes, but still a substantial majority of students indicated these skills were likely to be important to some or to a great extent. Table 5 shows a summary of the percent of students who anticipated the various engineering skills and knowledge covered in the SEED cases would be important "to some extent" or to "a great extent."

Table 5. Percentage of students indicating engineering skills would be important in their future careers to some or to a great extent

To what extent do you anticipate that the following engineering skills will be important in your future work as an engineer? *(Scale: 4 pt – Not at all – A great extent)*	
Skill/Knowledge	**Percentage "to Some Extent" or "to a Great Extent"**
Represent engineering problems from multiple different perspectives	93.7%
Identify social impacts of engineering decisions	93.1%
Describe the perspective of one or more stakeholders within and/or impacted by an engineering project	93.1%
Analyze tradeoffs in engineering decisions that impact internal and external stakeholders in disparate ways	91.9%
Recognize the complex interlocking systems in which engineering problems are embedded	91.3%
Suggest next steps, problem-solving pathways, or solution ideas that attend to diverse stakeholders	90.3%
Recognize and mitigate barriers to collaboration on diverse teams	89.1%
Weigh complex ethical considerations	88.2%
Identify ways that bias plays out in engineering practice	87.4%
Describe the interplay between social, contextual, and technical aspects of engineering work	86.5%
Identify ways that differences in identity, background, and power shape engineering processes and/or outcomes	82.5%
Explain how your own identities, backgrounds, and experiences shape how you approach engineering work	76.5%

Students rated their level of agreement related to the content and delivery of the case study lessons. The percentages shown in Table 6 represent that a majority of students had positive reactions to the use of the case study in students' engineering courses.

Table 6. Percentage of students who agreed with statements about their interest, values, and motivations related to case study lessons

Statement	Percentage Agree or Strongly Agree
Engineering training [at my institution] should include more content like that covered in the case study	66.8%
Engaging in the case study was a worthwhile use of my class time	67.1%
I enjoyed completing the case study	62.8%
The case study content was well-aligned with my interests in engineering	60.1%
I found the case study content to be motivating as an engineer	57.1%

Students' open-ended reflections on what they appreciated about the case study offer further insight into how its content and delivery supported engagement and learning. A key theme that emerged was the relevance of the case study to students' current coursework and interests in engineering. Many students described how this alignment helped them engage more deeply with the material. One student noted:

> *"I liked the fact that the case study was topical and relevant to the class that we were in, which allowed us to engage with it better."*

Another student similarly appreciated that:

> *"The topic was both interesting and directly related to the class. We are currently making autonomous drones, so including content about how autonomy functions is very nice. It is good to have presentations that correlate directly to what we are learning in class."*

Students emphasized how the case study helped them make connections between theoretical course content and real-world engineering applications. One wrote:

> *"I think it was pretty cohesive to what we were learning in class and it was nice to see some real life applications being applied, especially to something that everyone has some prior knowledge about."*

Another reflected, "I liked how the study related to the course content and was able to see how what I was learning applied in the real world." These sentiments were echoed by students who highlighted the value of seeing classroom concepts illustrated through specific examples: "Relating it to our coursework was the most impactful," one student explained. Another shared, "I liked how the lecturer connected the case study to the content we were learning by using the oil drip cup as an example problem."

Another theme in students' responses was the value of seeing how engineering concepts applied beyond the classroom. Students referenced the "real world" relevance of the case study as a key reason for their engagement. As one student put it, "I liked the real world component of the case study, as it helps apply what we are

learning in class." Others echoed this sentiment, with one student noting, "We got to see engineering concepts applied in a real world situation," highlighting how the case grounded abstract ideas in practical contexts.

The format of the case study itself also played a role in students' positive reception. Students said that presenting material in a narrative or applied context helped them better grasp and engage with complex engineering topics. One student explained that:

> *"By presenting the information in a case study, it gave real-world examples that were far easier to understand and think critically about."*

Others valued the way the content allowed for consideration of multiple perspectives. As one student shared, "I liked we got to experience multiple perspectives," suggesting that the format encouraged reflection on a range of viewpoints.

Students also described the pedagogy of the case study lesson—particularly the interactive elements—as key to their learning and engagement. The opportunity to discuss ideas with peers in both small and large group settings was especially appreciated. One student wrote:

> *"I liked the interactive activities to discuss our thoughts with our peers because it helped me to further my understanding about the information discussed in the case study."*

Another similarly noted, "The working within your group to enable collaborative ideas to come to mind and hear different perspectives."

Students also credited the facilitators and instructors for creating an open and thoughtful learning environment. Others highlighted the effectiveness of the presenters themselves. For some, having their professor lead the lesson was particularly impactful:

> *"I enjoyed having Professor... teach the content because it felt more relatable and he applied the engineering concepts in an engaging way."*

As one student summarized, the lesson was "a totally different lesson that needed to be learned in engineering, which didn't involve numbers or physics but rather unfortunate human behavior and bias."

Students were also asked to provide suggestions for ways the case study lessons could be improved. Many students did not write suggestions for changes or said they did not think anything should be changed. However, some students offered suggestions that they thought would improve their and other students' experiences.

A common theme among student responses with suggestions was a desire for more in-depth context, additional real-world examples, or updated information that could deepen their understanding of the engineering issues at hand. One student suggested that expanding the scope of case examples could enhance the relevance and impact of the lesson:

> *"I like learning about Hurricane Katrina and the engineering implications, but if we could see more projects and more real life situations in which the engineering needs to be carefully constructed as it affects real people."*

Others wished the content had gone beyond general discussion to include more concrete details. As one student noted: "The case study content could have covered

more specifics than just general information." Another specifically asked for a more detailed look at the experiences of individuals featured in the case materials:

> *"I wish the article... went more into the inventor and detailed his work a lot more like the things he made and how his life was changed after making the first invention."*

These responses suggest that some students were eager to explore the case topics even more deeply, particularly through richer narrative detail and additional real-world examples.

Some students expressed a desire for clearer alignment between the case study content and the technical material they were learning in class. While many found the case study interesting, several noted that it felt somewhat disconnected from their ongoing coursework, which limited its perceived relevance. One student explained:

> *"I think that it was a bit out of the way compared to the class content. The timing of this happened while we were deep in classes to do with more technical content... To give us this problem to think about now felt like a big change in direction."*

Others echoed this concern, suggesting that the lesson may have resonated more if introduced earlier in the term or when students were less overwhelmed. Another student shared:

> *"We were confused as a class why we were completing it because there was no context before it and it was quite different from what we were currently learning."*

Some students wanted the case study to have more emphasis on what they defined as the "engineering" of the topic. For example:

> *"I would have liked to see a bit more technical discussion that is more closely related to the content of the class being presented in."*

Several noted that the case study felt lacking in technical rigor. One student shared:

> *"I think the case study could have included more engineering content or been taught from more of an engineering perspective. It seemed to be a very surface-level analysis of pulse oximetry and could have been a more in-depth analysis if more engineering content had been included."*

Others echoed this sentiment, suggesting that while the social and design aspects were compelling, they would have preferred a stronger engineering focus overall: *"The content could also be more engineering focused rather than just social impact."* These responses suggest students desired clearer integration of the case content with the course's technical focus and a framing that connected it more clearly to how they thought about engineering.

Across more than 300 student responses, only a small number—three in total—expressed strong opposition to the inclusion of the case study in their engineering course. For example:

> *"I would like to hear a real lecture covering real engineering. This covered nothing technical or analytical for engineering."*

These students felt the content was unrelated to engineering and viewed the lesson as an inappropriate use of class time.

In some classes, students noted that the case study was not directly connected to course assessments, such as homework assignments, quizzes, or exams. As a result, some perceived the lesson as "extra" rather than an integral part of their learning. Without a clear tie to graded work, students reported feeling less motivated to engage deeply with the material. One student explained

> *"We have a two hour class period, this presentation really shouldn't have taken the full two hours. You have a group of students that is already depleted from normal because many people realized we wouldn't really be learning anything we would be tested on... it really could have been [shorter], and may have helped with engagement."*

In these cases, the absence of assessment contributed to students viewing the case study as less essential or relevant to their academic priorities.

Students also shared feedback on the structure and delivery of the case study materials. In some instances, students felt that the pre-reading assignments overlapped too heavily with the in-class content, leading to redundancy. As one student noted

> *"I would probably not assign this as homework before the lecture. During the lecture, it felt repetitive a bunch because the homework was the exact same thing."*

At the same time, others emphasized the importance of a brief in-class summary, recognizing that not all students may come fully prepared:

> *"Something to consider is assuming that a lot of students didn't read the entire case or comprehended the entire case so a quick recap at the start of the presentation couldn't hurt."*

Students also offered case-specific suggestions for improving clarity and engagement—such as revising handouts, incorporating more visual elements, and providing additional viewpoints. One student suggested, "Add videos or other formats to show [to] make the experience more immersive," while another wrote:

> *"I would have liked more perspectives shown. We focused on one particular person, but I would have rather had multiple people so that I would be able to understand more of the societal context and how it affected other people."*

A few students also expressed concern about when the case study was scheduled, particularly when it was held close to the end of the semester: "Time. It took place only a few lectures before the final."

Within feedback for improvement, many students emphasized their appreciation for the case study format and expressed a desire to see more of this kind of content in their engineering education. One student wrote:

> *"I hope case studies like this one can be implemented in more of the Mechanical Engineering courses, because I believe these topics are important to discuss and it only took one class period to cover."*

Others noted that repeated exposure to such lessons could help create more open and thoughtful classroom environments, especially when dealing with sensitive or unfamiliar topics. As one student reflected:

> *"I think it was great just not sure how to make more people comfortable because it wasn't the environment but it felt like the information made people uncomfortable which is a deeper issue. I think the solution may be to do more case studies and incorporate them into more classes."*

These comments highlighted students' interests in expanding opportunities to engage with complex, real-world issues through structured, discussion-based learning.

4 DISCUSSION AND IMPLICATIONS

Engineering educators have for years sought to advance student learning of socially engaged engineering skills and knowledge, exploring strategies to integrate socially engaged engineering content into the curriculum [23], [24]. Our findings highlight the effectiveness of leveraging real-world case studies integrated into existing engineering courses as one such strategy to support students' learning. Student survey responses suggested that a substantial majority of students felt that the SEED case studies advanced their understanding of multiple socially engaged topics previously identified as crucial for effectively accounting for the sociotechnical realities of engineering work [1]–[4]. Specifically, students most frequently named the SEED case studies as advancing their skills or understanding related to the societal impacts—both positive and negative—of engineering decisions, the need to understand and ability to account for a wide range of stakeholder perspectives, and the complex interplay between multiple social, contextual, and technical dimensions in engineering problems. Students also described the cases as helping them understand the nature of "real-world" engineering problems and specific tools and resources that can be leveraged in solving sociotechnical engineering problems.

When presented with a list of specific socially engaged engineering competencies, a substantial majority of students (ranging from 76–93%) perceived these skills to be relevant to their future work, suggesting overall recognition of the sociotechnical breadth of engineering practice among those students who had completed one or more case studies. Further, a majority of students expressed positive perceptions of the SEED case studies and the benefits of engaging with such content in their engineering coursework. Most students agreed that case studies were enjoyable, a worthwhile use of class time, aligned with their interests, and motivating, and that more of this type of content should be included in their undergraduate training. Students described particularly appreciating when case studies felt clearly connected to other course topics and explained that these course-relevant cases helped them understand applications of course principles in real engineering practice and provided additional insight into what professional engineering work could entail. These findings align with prior research by Chen and colleagues [56], who found that engineering lessons that emphasized the "who" of engineering, including who is impacted, whose problems are addressed, and the type of engineers students want to be, were more memorable for students and suggested that emphasizing the sociotechnical nature of engineering practice can help support student engagement and encourage reflection on future career goals.

Our findings also point to the ways some students may struggle to reconcile socially engaged engineering topics with the persistent ideology that positions "real" engineering work as narrowly technical and removed from social or political realities [9]–[10], [17]–[18]. While only three students expressed a strongly negative reaction to the cases as wholly irrelevant or inappropriate to include in engineering coursework, several other students expressed a desire for greater emphasis on the technical—or what they referred to as 'engineering'—aspects of a given case. Consistent with tensions documented in prior scholarship (e.g., [5], [21], [62]), these student responses signaled a distinction between socially engaged dimensions and technical skills and knowledge that students understood to be the central or most legitimate purview of engineering practice.

Relatedly, some students expressed a perception that the case studies felt disconnected from the content of the rest of their course, with several of these students pointing to the way the case study was presented as contributing to their perception of its relevance. In some instances, students expressed a desire for more explicit framing of the case study from the primary course instructor as it related to other course topics or described the case study as a one-off lesson, not referred to outside of a single course session or reinforced through assessment. Prior scholarship, including literature that informed our development of the case studies and their implementation approach, highlights the important role of pedagogy in supporting students in recognizing the relevance and facilitating their development of socially engaged engineering skills and knowledge. Specific considerations include:

- Integrating socially engaged topics throughout a course, offering multiple chances for students to engage with topics and reinforce their learning [42], [63]
- Making explicit the connections between socially engaged content and technical course topics and goals [2], [42], [64]
- Including socially engaged topics as part of the graded assessments for a course to reinforce their importance and provide an opportunity for students to reflect on or apply concepts [16], [42], [65].

The feedback shared by students in the present study serves to reinforce the importance of ensuring that socially engaged engineering topics are taught in a way that does not position them as distinct from and extraneous to other technical course topics and directly informed efforts among our own team to work with partner instructors as needed to help them more explicitly situate case studies within their course contexts. Working with more instructors to integrate additional course-relevant technical details into the cases themselves offers an additional opportunity to help students see more concretely the interconnections between technical, social, and contextual considerations in engineering problems.

In order to best prepare students for the sociotechnical realities of engineering practice and, as a field, move beyond overly narrow conceptions of engineering as a strictly technical endeavor, it is important that socially engaged dimensions of engineering are integrated consistently across the engineering curriculum [23], [24]. While this approach may be increasingly recognized as given among many scholars of engineering education, our findings highlight that students, too, see the importance of socially engaged skills and knowledge for their future engineering practice, and many want additional opportunities to engage with these topics in their undergraduate studies. Several participants expressed that a more consistent emphasis on socially engaged engineering content throughout their curriculum would help normalize discussion or consideration of these topics in engineering. Socially engaged

engineering topics are more frequently incorporated into design-focused introductory and capstone courses that bookend students' studies, offering opportunities for students to engage in contextualized problem-solving and a consideration of both technical and socially engaged aspects of engineering [26]–[28]. Case studies, or related module-based approaches (e.g., [40]–[42]), present an opportunity for integrating these topics into engineering science courses, which tend to emphasize a narrower scope of engineering problem-solving contexts [39]. Students' generally positive responses to and reported learning from the SEED case studies, which were implemented across a range of design and non-design courses, disciplines, and years of undergraduate study, highlight the potential of well-supported case studies as a strategy for advancing broader integration of socially engaged engineering topics throughout the engineering curriculum.

5 CONCLUSION

This study demonstrates that integrating microhistorical, socially engaged engineering case studies into existing undergraduate curricula is a powerful strategy for broadening students' perceptions of the engineering profession. By framing technical achievements within their broader sociotechnical realities, the SEED modules effectively advanced student understanding of human complexity, systemic trade-offs, and embedded engineering biases. The overwhelmingly positive feedback indicates that modern engineering students are highly motivated by real-world applications that emphasize the human and community impacts of their work. Furthermore, the successful deployment of these modules across both design-focused and engineering science courses demonstrates that contextualized, socially engaged competencies can be scaled effectively across an entire engineering department without requiring extensive structural overhauls.

However, the findings also highlight critical pedagogical challenges that educators must navigate to successfully counter deep-seated technocentric framing. A minor faction of student resistance and confusion emerged when case studies were treated as isolated, "one-off" lectures separated from core course assessments and explicit instructor framing. To optimize the impact of socially engaged engineering curricula, future implementations should purposefully integrate these sociotechnical engineering exercises into graded assignments, connect them directly to technical content, and introduce them early in the academic term. Normalizing these discussions through repeated exposure and explicit scaffolding supports future engineers in viewing attention to societal and environmental contexts, human perspectives, and the broader impacts of engineering decisions not as peripheral burdens, but as foundational elements of excellent engineering practice.

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8 APPENDIX A: SURVEY INSTRUMENT

8.1 Case study learning

For the following items, please indicate the extent to which the case study (or studies) you completed expanded your knowledge or understanding of the following engineering skills:

Note that case studies may not relate to all of the following skills, so if you believe a topic was not at all touched on in the case study you completed, please select "This topic wasn't covered."

Scale: *Not at all, To a small extent, To some extent, To a great extent | This topic wasn't covered*

- Describe the perspective of one or more stakeholders within and/or impacted by an engineering project
- Analyze tradeoffs in engineering decisions that impact internal and external stakeholders in disparate ways
- Describe the interplay between social, contextual, and technical aspects of engineering work
- Recognize the complex interlocking systems in which engineering problems are embedded
- Represent engineering problems from multiple different perspectives
- Identify ways that differences in identity, background, and power shape engineering processes and/or outcomes
- Explain how your own identities, backgrounds, and experiences shape how you approach engineering work
- Recognize and mitigate barriers to collaboration on diverse teams
- Identify social impacts of engineering decisions
- Weigh complex ethical considerations
- Identify ways that bias plays out in engineering practice
- Suggest next steps, problem-solving pathways, or solution ideas that attend to diverse stakeholders

8.2 Relevance to future work

To what extent do you anticipate that the following engineering skills will be important in your future work as an engineer:

Scale: *Not at all, To a small extent, To some extent, To a great extent*

- Describe the perspective of one or more stakeholders within and/or impacted by an engineering project
- Analyze tradeoffs in engineering decisions that impact internal and external stakeholders in disparate ways

- Describe the interplay between social, contextual, and technical aspects of engineering work
- Recognize the complex interlocking systems in which engineering problems are embedded
- Represent engineering problems from multiple different perspectives
- Identify ways that differences in identity, background, and power shape engineering processes and/or outcomes
- Explain how your own identities, backgrounds, and experiences shape how you approach engineering work
- Recognize and mitigate barriers to collaboration on diverse teams
- Identify social impacts of engineering decisions
- Weigh complex ethical considerations
- Identify ways that bias plays out in engineering practice
- Suggest next steps, problem-solving pathways, or solution ideas that attend to diverse stakeholders

8.3 General perceptions of the case study

Please indicate the extent to which you agree or disagree with the following statements about the case study (or studies) you completed in your course(s).

Scale: *Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree*

1. The case study content was similar to the content of many of my engineering courses
2. The case study covered relevant engineering skills and knowledge
3. The case study contributed positively to my understanding of real engineering work
4. The case study covered engineering skills and knowledge that are important for my future engineering work
5. The in-class facilitation of the case study helped my understanding of the material
6. I enjoyed completing the case study
7. Engineering training at UM should include more content like that covered in the case study

What are 1–2 things you learned from the case study in your class? (Open response)

What did you like or think worked well about the case study content, format, or facilitation? (Open response)

What would you have liked to be different about the case study content, format, or facilitation? (Open response)

Do you have any additional thoughts or feedback related to the case study you completed? (Open response)

8.4 Engineering future plans and demographic information

Future employment: immediately following graduation, which of the following are you most likely to pursue as your primary position? [Select one]

- Working for an engineering-focused company (at least 50% focus on engineering practice)
- Working for a multidisciplinary company (engineering accounts for 50% or more of the company's activities)
- Working for local, state, or federal government
- Working for a non-profit or non-governmental organization
- Entrepreneur/start your own company
- Graduate study in engineering
- Graduate or professional school in a field other than engineering
- Military service
- Other (please specify):

Is there anything else you would like to tell us about your plans post-undergrad? (Open response)

What is your current year in your undergraduate studies?

- 1st year
- 2nd year
- 3rd year
- 4th year
- 5th+ year
- I am a graduate student

Have you declared a major?

- Yes (please specify): _____
  _____
- No, but I have a good idea of what major(s) I will choose (please specify): _____
  _____
- I have not declared a major, nor am I certain what major(s) I am most interested in

How would you describe your gender identity? (open response)

How would you describe your racial/ethnic identity? (open response)

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