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Investigating an Asynchronous Model for Incorporating Social Aspects of Engineering Work into Engineering Design Courses*

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This paper describes an implementation study of the Social Engagement Toolkit (SET), a library of trainings on various topics related to socially engaged design and engineering. The customizable SET trainings include asynchronous hybrid learning blocks intended to facilitate instruction on socially engaged engineering topics by non-expert instructors in a range of engineering courses, as well as live expert instruction and entirely virtual instruction, developed for online courses in the 2020–2021 academic year. The SET seeks to foster much-needed socially engaged engineering skills among undergraduate engineering students, while addressing potential barriers to curricular change, such as instructor motivation and prior training. We examined the incorporation of the SET into multiple sections of a senior-level capstone course and a project-based introduction to engineering course to understand the experiences of early adopter faculty and their students. This paper describes faculty's motivations for and their experiences with implementing the SET in their classes, strengths and challenges of the toolkit, and the perceived influence on and relevance to students' course work and future academic and professional plans.

Keywords: instructional change; engineering design; socio-technical thinking

1. Introduction

There is growing recognition that engineering is necessarily both a technical and social discipline [1–3]. In order to be successful, engineering solutions must be both technically sound as well as desirable and feasible when considering stakeholder priorities, contextual dimensions, and consequences at local and global scales [4, 5]. Though social and contextual-focused skills required for socially engaged engineering are critical, they are typically underemphasized in curricula [6, 7]. We refer to these skills – related to conducting engineering work from a holistic and inclusive perspective by gathering, utilizing, and equitably applying rich and diverse contextual information about stakeholders, communities, ethics, the environment, and economic – as socially engaged engineering skills. An underemphasis on socially engaged engineering skills persists despite the fact that ABET and national reports highlight such skills as essential to the future of the profession and the success of the work done by engineers, and as equally important to more widely recognized technical engineering skills [8–10]. Often in engineering, there is a distinction made between "technical" and "non-technical" dimensions of engineering practice, suggesting social and contextual-oriented dimensions of practice are less important than, and able to be disentangled from, technical considerations. We acknowledge the power of this framing in shaping engineering practice and teaching, but "technical" and "non-technical" engineering considerations are inextricable from one another and equally important.

In some engineering work experiences, students may be aware of the relevance of cultural, social, economic, and political contexts at a high level, but they often struggle to incorporate these aspects in practice and lack self-awareness about their own biases, lenses, and norms [11]. This deficiency arises not only from lack of exposure to the social sciences and humanities during formal engineering education, but also from implicit messaging when, for example, technical expertise and outcomes are prioritized in engineering projects, or when community members or experts in other non-STEM fields are not fully engaged in collaboration in engineering development work [12]. While some students acknowledge the value of engaging with stakeholders in their engineering problems, they may not understand how to do so and with whom to consult. Prior research highlights that students may not recognize a need to engage stakeholders beyond their specific clients [13], or, when they did engage more broadly, lacked the methods, tools and best practices doing so effectively [13, 14] and struggled to incorporate stakeholder input within their design decisions [15].

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Students require explicit training to overcome these issues. If students do not identify the "real problem" through a deep understanding within the complex engineering problem solving context, they are unlikely to create successful solutions [16, 17]. Research shows that student engineers have difficulty collecting and interpreting relevant information about users, stakeholders, and context [15, 18] and they may miss contextual factors that will impact success [18, 19]. Students need assistance and support to develop solutions that integrate a rich understanding of a problem within its context. The inclusion of deep knowledge of users, stakeholders, and environmental impacts, in addition to a deep understanding of technical dimensions of a problem, can then help to guide idea generation and problem solving, leading engineers towards more innovative results [20]. The contexts for an engineering problem – physical, personal, social, cultural, and societal – can be a rich source of information to help students develop options that are practical and useful within the actual setting. Paradoxically, the additional constraints on ideas arising from contexts serve to promote (as well as preclude) alternative concepts [21], focusing attention on solutions in more novel areas than the obvious possibilities. When the problem solving process leads engineers closer to the lived experiences of the human stakeholders, engineers can understand and develop solutions that truly meets people's needs [22].

To teach students about social and contextual factors in engineering work, most instructors today need new vocabulary, teaching tools, practice examples, and exercises compatible with their own specialized expertise and their existing course environments. In addition to appropriate tools and training, instructors must be interested in teaching social engagement skills. Embracing the need for training in socially engaged engineering skills may be challenging for educators trained to stress technology and mathematical analysis over applications fulfilling needs; while the field of engineering is segmented based on technical domain, instructors are beginning to recognize the gap between knowing how to solve problems and knowing whether those solutions are appropriate for the application contexts. Instructors' resistance to curricular change often stands at the intersection of individual and structural factors [23–25]. Instructors may have deeply embedded assumptions and values around pedagogy, possess a limited understanding or experience of alternative approaches, and feel uncomfortable working outside of their own technical expertise. Challenges are compounded when institutions do not incentivize dedicating time to developing curricular materials and when instructors feel they are not given adequate training, resources, and support as they implement new approaches. Across disciplines, individual autonomy is a dominant feature in instructors' educational training and work; consequently, they are protective of their courses and their discretionary time [26], and instructors in "hard sciences" may be especially likely to resist change [27]. Instructor buy-in is a foundational challenge to any attempt to transform engineering pedagogy [28]. Making an effort to understand initial instructor resistance to change can promote ongoing instructor conversations that lead to necessary adaptations and revisions of change agents' proposals [29–30].

Meaningful institutional change starts with a nuanced understanding of the problem and its context [31]. Research on STEM reform suggests that change agents' efforts are hampered by their desire to enact interventions without fully engaging the underlying issues [32]. In educational innovations, instructors' norms around teaching and receptiveness to evidence-based teaching practices may vary considerably among STEM departments, even on the same campus [33]. Researchers call for change agents to first understand the specific barriers and drivers for change at the department level [24]. STEM reforms are more likely to succeed when a cross-section of instructors collectively agree upon curriculum-wide goals and embed changes within a coherent structure [34].

This paper details efforts at the University of Michigan (UM) to develop an easily adapted and deployed approach to fostering students' development of socially engaged engineering skills and characterizes faculty and students' early experiences with that approach. Working with UM's Center for Socially Engaged Design (C-SED), members of our team developed the Social Engagement Toolkit (SET), a collection of resources, including on-demand lessons on a variety of socially engaged engineering topics from which non-expert instructors can select and use to use in their courses. We provide an overview of the SET and describe findings from an initial assessment of SET deployment among early adopters in multiple sections of both a first-year introductory engineering course and a senior engineering design capstone course. Understanding the experiences of these early adopters and their students can be used to further refine the SET, provide insight into key strengths and challenges of the SET that may facilitate (or hinder) adoption of the materials by other instructors and in other institutional contexts, as well as inform other efforts to integrate social dimensions of engineering work into engineering education coursework.

2. Social Engagement Toolkit

UM's Center for Socially Engaged Design was founded in 2015 with the purpose to provide expertise, educational resources and programs, and space for students and instructors to engage in social and contextual elements of engineering work alongside the technical elements of engineering work [35]. C-SED defines their approach as "human(ity) centered," explaining "We consider broad contexts through an equity-centered lens that impact the practice of engineering, including social, cultural, political, economic, and environmental factors that can completely change the design of solutions. Further, we push designers to analyze how their own identities and cultural context shape their approach." C-SED offers research-informed content (with instructional support) that is intended to be adaptable to a range of contexts and instructional needs. The hallmark educational offering described in the present paper is the Social Engagement Toolkit (SET). The SET includes curricular materials that use a hybrid learning approach consisting of modular learning blocks on a variety of topics [36]. The learning blocks typically include on-demand lessons and in-person or synchronous virtual coaching for learners, an adaptable approach that proved key in a university-wide move to online instruction during the COVID-19 pandemic.

The SET is designed to train undergraduate engineers in the skills needed to develop technical solutions that will be both effective and adopted within the social contexts of their intended use. SET training empowers students to actively incorporate context into problem definition, solution generation, development and prototyping, and testing and refining stages of engineering practice. In order to disseminate information and practice the required skills addressing many levels of social contexts, the SET pools the knowledge of many experts experienced in varied contexts for student training. This learning model ensures that no one engineering instructor needs to master the myriad of skills needed to holistically instruct their students; instead, the examples, practice problems, guidelines, and principles around how to engage in social contexts are provided to students without requiring instructors to provide specific expertise.

Instructors can preview the SET library of resources before integration into their course plans, and coaches can assist instructors in adapting materials to their courses. The SET library currently includes topics such as ethnographic analysis, conducting interviews, stakeholder impact assessment, making field observations, project organization and management, concept development, idea generation and co-design, user requirements, accessibility, specifications, sustainable development, managing differences in power and identity, and inclusive engineering, while new examples and topics are under development.

Each hybrid learning block in the SET includes five primary elements (shown in Fig. 1): (1) Prior Knowledge Review prompts students' reflection on their relevant past experiences, preconceptions about the topic, and motivations for learning. (2) Core Content supports self-study by outlining learning objectives. Key concepts are described through a combination of readings and videos using real-life examples to illustrate relevance and to help with translation across engineering problem solving contexts. (3) Knowledge Check tests students' foundational knowledge through both open-ended and multiple-choice questions. Students receive feedback on responses from trained graders through the online platform. (4) The Application tasks provide opportunities to work with key concepts within new contexts in real-life scenarios. Here, students meet either in-person or virtually with coaches to receive individualized feedback; then, they revise their initial responses. (5) Reflection allows students to consider how their pre-existing ideas have changed, what new knowledge they have gained, and how they might apply concepts in their future work. This foundational structure can be adapted based on the context of implementation and the goals of the instructor.

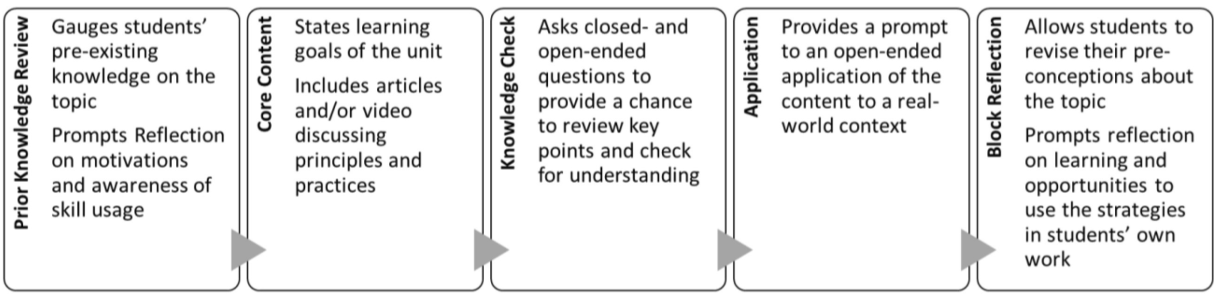

Fig. 1. Key Elements of SET Learning Blocks.

In our team's prior research, we tested the impact of the SET hybrid learning blocks on various social engagement skills. In one study, engineering students who were part of a co-curricular organization working on assessing needs in a community completed SET hybrid learning blocks on needs finding and assessment as well as stakeholder interviewing [37]. Our data analysis demonstrated that the hybrid learning blocks supported students in: (1) identifying how their engineering backgrounds potentially influenced their perceptions of community needs; (2) recognizing the value of interacting with a diverse range of stakeholders when identifying needs; and (3) including local partners in the needs identification process. The study also revealed some struggles students experienced, such as leveraging a variety of data collection methods strategically and analyzing their complex data effectively, which guided our iterations of the hybrid learning blocks on needs finding and assessment to its current form.

In another study, engineering students were asked to prepare and execute an interview with a provided mock stakeholder for a given problem [36, 38]. We recorded participants' interviews with a mock stakeholder for a given task before and after they completed the learning blocks on stakeholder interview preparation and stakeholder interview execution. We also interviewed the participants about their experiences. Data analysis revealed significant increases in particular stakeholder interviewing behaviors that align with best practices for gathering deep information about stakeholder experiences and perspectives. We also found that students, after completing the learning blocks, demonstrated a more diverse range of interviewing behaviors aligned with best practices.

In a study on engineering students' approaches to concept generation, development, and selection practices during a human-centered problem solving process [39, 40], members of our team executed a series of think-aloud experiments where they asked participants to generate, develop, and select concepts for a given engineering problem. Students then completed the hybrid learning blocks on approaches to concept generation, development, and selection. Our analysis compared the approaches students used before and after completing the hybrid learning blocks. Key differences occurred in student approaches after completion of the blocks; for example, they generated more unconventional ideas, avoided form requirement assumptions early in ideation, generated a larger number of ideas, used more intentional strategies in developing ideas, and used more rigorous concept selection methods. These outcomes aligned with the core content in the hybrid learning blocks.

3. Study Design

In the present study, we aimed to understand the strengths and challenges of the rollout of the SET materials. As the SET was designed to be adaptable to a range of educational contexts, the present study details its use by early adopters in multiple sections of two courses: a senior engineering capstone design course (referred to as CAPSTONE in this paper) and a first-year introduction to engineering design course (referred to as INTRO). Both courses involved a semester-long engineering design project that students worked on in teams in addition to (and ideally informed by) the SET modules they completed. Though the context of the shift to online learning changed some aspects of the delivery, including the lack of in-person discussion and a need to adapt the focus or flow of the course in some sections, the feedback we sought from students and instructors emphasized long-term educational demands and factors shaping potential adaptation or scalability of the SET. More specifically, we hoped to learn about instructors' initial interests in employing SET content, the benefits and challenges they experienced in doing so, the relevance of SET content both to students' work in the course and their future academic and professional careers, alignment of SET content and course goals, suggestions for improving the learning blocks within the SET, and feedback related to the potential usefulness and scalability of the SET in other educational contexts.

3.1 Contexts of SET Implementations

The two contexts of SET implementation explored in the present study differed both in how the SET came to be adopted and the specifics of the implementation. In INTRO, individual faculty served as early adopters, working with C-SED to identify and tailor SET content for their individual courses. Several instructors utilized one or two learning blocks over the course of the term while others used five or more on a wide range of topics. These instructors utilized hybrid instruction, typically relying on synchronous virtual facilitation from C-SED staff in conjunction with written materials and activities. One instructor opted for asynchronous instruction, with pre-recorded content from C-SED facilitators in addition to written lessons and activities adapted to the class's particular project focus.

CAPSTONE represented a unique case in which the lead instructor who oversaw multiple sections opted in and customized SET content to be utilized in all sections of the courses in both Fall 2020 and Winter 2021 terms. Because this decision was made and implemented centrally as a common

Table 1. CAPSTONE SET Modules and Goals

SET Module	Module Goal
Design Process Overview	Introduce a variety of design processes, highlight the importance of using a structured process for design work, and provide a suggested framework for CAPSTONE design project activities.
Problem Definition	Highlight the importance of problem definition and provide students with the best practices for developing a complete and correct set of requirements and specifications.
Concept Exploration	Highlight recommended practices in concept generation, concept development, and concept evaluation.
Engineering Inclusivity	Help students explore who they are as engineers and the power they have with respect to users and other stakeholders through their work and learn strategies for making more inclusive design decisions.
Environmental Context Assessment	Demonstrate why designers should consider the environmental context of technologies when doing design work and to provide students with tools to help them evaluate the potential environmental impacts of their designs.
Social Context Assessment	Demonstrate why designers should consider the social and economic context of technologies when doing design work and to provide students with tools to help them evaluate the potential social and economic impacts of their designs.
Ethical Decision Making	Demonstrate why designers should consider the ethical responsibilities of their design work and to provide students with tools to help them evaluate the potential ethical impacts of their designs.

curriculum for all CAPSTONE students, individual section instructors had different degrees of familiarity with the SET and its content. A total of seven SET modules were utilized in CAPSTONE including: Design Process Overview, Problem Definition, Concept Exploration, Engineering Inclusivity, Environmental Context Assessment, Social Context Assessment, and Ethical Decision Making. A brief description of each module is included in Table 1.

In the CAPSTONE context, students worked independently on virtual SET lessons at their own pace and submitted their application tasks and reflections for constructive feedback. An example application task from the Social Context Assessment learning block is available in the Appendix. The learning block format used in CAPSTONE differed from the typical learning blocks format in that it did not include an in-person or synchronous facilitator. The independently completed SET modules in CAPSTONE replaced weekly lectures, which had previously been attended by students in all course sections, though the lecture content varied from term to term. The move to SET curriculum aimed to provide all students with a common knowledge base and the virtual-only format offered flexibility in light of constraints posed by the COVID-19 pandemic.

3.2 Data Collection and Analysis

In order to explore how the SET worked in different contexts and factors that could influence its uptake or continued use, we conducted interviews with faculty teaching SET content in both CAPSTONE and INTRO courses, as well as students enrolled in CAPSTONE. Faculty were recruited for participation in the study directly via email based on their use of the SET in their courses. CAPSTONE students were recruited via a course site announcement that shared a link in which interested students could use to sign up for study participation. We sought to interview students across multiple sections of the CAPSTONE course. All data was collected following the university's human subjects research requirements. Across the two courses, our team collected 11 faculty interviews and 16 student interviews.

To avoid revealing the identity of individual participants, we only report summary-level participant background information. Of the 16 CAPSTONE students we interviewed, 10 identified as men and six as women. Nine of these students identified as White, four as Asian, one as Middle Eastern, one as Hispanic, and one as Biracial. They were enrolled in 9 different sections of the course across two semesters and were engaged with team projects on a wide range of topics. We did not explicitly ask faculty participants about their gender and racial identities, but they represent a range of social identities and academic backgrounds.

Interview development was guided by our research interests and revised for clarity and focus based on feedback from several faculty and staff members aware of the SET and project goals. Examples of questions for faculty included:

- How did you first come to use [SET content] in your course? What drove that decision?
- What do you think the biggest challenge of implementing the blocks was for you as an instructor?
- I'm curious to hear your thoughts broadly on the content and scope of the learning blocks, given your learning goals for the course. Did they cover the right amount of material and right topics?
- Do you think the learning blocks shaped

students' course projects in any way? If so, how? If not, why do you think that was?
- What would you do differently in the future in terms of moving forward with the blocks?

Student interviews included questions such as:

- To start us off, could you tell me a bit about your overall impression of the learning blocks used in your CAPSTONE course this semester?
- How relevant did the different blocks seem to the engineering work you plan to do in the future?
- How did the learning blocks compare to your previous engineering training?
- Generally speaking, what could be improved about the learning blocks? Are there particular things that would you change?

Interviews were conducted virtually via Zoom and lasted roughly between 30 and 70 minutes. Student participants were compensated $25 for their time to incentivize their participation. Interviews were transcribed for analysis using the Rev.com transcription service.

One team member led data analysis efforts by first reading through all interviews and noting general themes. She then conducted a series of thematic analyses, looking at CAPSTONE instructors, CAPSTONE students, and INTRO instructors as three distinct sets of data, summarizing findings within each related to a series of key topics and compiling supporting interview excerpts for each. For example, key topics from instructor interviews included: instructors' decisions to use the SET and their initial reactions, qualities of the SET that encouraged use, challenges of the SET and potential barriers to use, selection and fit of content, instructor role in facilitating SET curriculum, impact on students' current work and future careers, and suggested changes. Then, based on this initial round of analysis, she compiled higher level summaries of common themes for each group, as well as an additional summary of themes common across all three groups. Other study team members then reviewed both the initial and more detailed analysis documents and higher-level summaries.

3.3 Study Limitations

We note several limitations of this study which may have shaped our findings. First, both faculty and students opted into participation in this study. It is possible that only those with positive experiences or who otherwise felt strongly about the SET elected to participate, potentially shaping the range of responses shared with our team. Second, our study characterized instructors' experiences with the SET across multiple course sections and use contexts and CAPSTONE students' experiences with different instructors. While this range of experiences provides insight into diverse interactions with the SET, looking across these contexts may also obscure aspects of how the SET was presented in particular contexts that shaped how students and instructors experienced the SET. Finally, our data collection centered on courses that utilized the SET during the 2020–2021 academic year in which there were a number of educational adaptations necessitated by the COVID-19 pandemic. While the SET learning blocks were designed as a hybrid learning model, instructors' and students' priorities and approaches to engineering education during this time may differ from those during other academic years.

4. Findings

An analysis of student and faculty interview data provided insight into key strengths of the SET modules, as well as ways they may be improved to further promote adoption across contexts. Faculty named a number of motivations for integrating the SET into their courses, noting its ease of use, alignment with their curricular goals, and adaptability. Students and faculty alike described SET's emphasis on socially engaged engineering to be largely missing from elsewhere in the engineering curriculum. Both groups also offered suggestions for how the SET might be improved for future use. This section describes these key findings in greater detail.

For instructors in INTRO sections who sought out the use of SET in their classrooms, the fact that implementing learning blocks in their classrooms was an easy lift, or even reduced their overall instruction effort, was a key motivation. For example, one junior faculty member explained: "To me, it makes no sense not to use already developed and proven modules on topics that relate to what I'm doing. Frankly, I'm stretched thin for time and I can say, 'Someone's already done this, it's good to go.'" In the CAPSTONE sections, in which most section instructors were not involved in the decision to implement SET curriculum, instructors still consistently described the learning blocks as requiring very little time or effort on their part. One instructor who had taught previous sections of the course argued, "I think, again, from the instructor side this is a no brainer, this is easy. You basically took, if you'd like, no effort at all. It's all there and your students are well informed as to when the learning blocks are assigned and when the assignments associated with them are due."

Another key factor driving faculty's implementation of the SET in their courses was the extent to which the materials aligned with their course goals and learning objectives. Within INTRO, instructors were able to work with C-SED staff to identify appropriate learning blocks from the SET library and even tailor them to their particular needs and circumstances. Instructors noted the content was appropriate for their students' current level of awareness and understanding. One INTRO instructor stated "I think what they were introduced to was appropriate for their level as first year students for and thinking about it for the first time and then creating questions," elaborating that they did not want their students to be "overloaded" at this early point in their studies. Other INTRO instructors described their enthusiasm about finding content through SET that aligned with topics they hoped to cover in their course, explaining that existing content eased their load as instructors by preventing them from "reinventing the wheel." One instructor described the benefits of SET content reflecting extensive curation of content on socially engaged design topics she hoped to teach, noting: "From my perspective, it was great to have people that already had content that was condensed and put together in a really clean nice way they already have amazing case studies."

In CAPSTONE classes, the lead instructor worked closely with C-SED staff to identify and develop SET modules to meet the particular learning goals of the course. Through extensive conversations among faculty, they identified a common set of topics for students in all sections of the course to foster key skills and knowledge. Though the individual sections of CAPSTONE differed in the extent to which they explicitly stressed socially engaged engineering principles (outside of the learning blocks) and individual instructor goals varied, several instructors noted the relevance of the SET modules to larger college- and nation-wide learning outcomes. As one instructor noted:

> "Having learning blocks and having assignments on those themes enables us as a department to document the learning on these themes of learning that are not focused in any one course. It's going to serve an important need in evaluation of our curriculum and, for example, the review by ABET, the accreditation review."

Many CAPSTONE students also described SET content as a strength, often contrasting the socially engaged focus of SET modules to the content covered in their other classes. Several students noted that the SET modules were the first place they encountered topics such as social context or inclusivity in their engineering training. One student explained that without the SET content they were uncertain where they might have learned about these social aspects, stating: "if the learning blocks weren't there, it was missing a pretty important component of talking about the social impacts of our projects and getting us to think about that, as well as the environmental impacts of our projects." Students also explained that they viewed the online SET modules as a repository for a range of resources that they might refer back to in future work. One student remarked that "it was a nice way to look at a summary of information, so instead of having to scroll through lecture slides or watch a lecture recording. Maybe as a means for just a repository of information for students to refer back to throughout the semester is kind of nice."

Given the range of course projects for students in CAPSTONE, students varied in the extent to which they perceived all aspects of the SET as directly applicable to their individual projects. While both students and instructors described ways the SET modules shaped project work, some students described the blocks that were due later in the term as happening too late in their project timeline to have a substantial influence. One student articulated that some of these later blocks served as "more of a check," explaining "by the time you get to the ethics block, it's like, well, we can't really change our process because we're most of the way done with our project." Other students expressed a desire for there to be more explicit linkages made between the SET modules and their specific course projects, with one student expressing concern that the blocks felt like an "afterthought" when not linked to rest of the work in the term. Despite these concerns, nearly all students described SET content as important for their future academic and professional engineering endeavors. One such student argued that, regardless of their path, they saw all topics covered by the learning blocks as relevant to their future work, explaining:

> "I'm not sure exactly as to what I would be doing in the future, but I do know that I would want to... I do know I would like to design products of some sort. And when it comes to designing products, not only do you have to think about, you have the whole design process, and how to make them more efficient, and what not. But also, how your decisions affect everyone else, and your consumers, and whatnot."

Students and faculty alike echoed this sentiment, pointing to the general relevance of SET content for engineering learning and practice.

Interestingly, instructors noted the SET's potential for both customization for specific course needs and standardization of key terms and principles across courses as strengths of the SET. Many instructors noted an advantage of the SET was the potential for standardization of content across courses, including as a way to ensure students learned a consistent set of principles and vocabulary. One instructor discussed how in previous years topics covered in CAPSTONE lectures varied by the expertise of the teaching staff that term, but using the SET enabled them to "deliver sort of a consistent set of expectations that all students taking CAPSTONE should have to understand and learn and know and then be able to apply that content to their project." Similarly, an INTRO instructor explained a desire for ensuring consistency in the language and concepts students learned around design as a key motivation for utilizing the SET, stating:

> "I was looking for a way to speak to this with the students without making it all kerfuddled, and I wanted to have the same vocabulary that they would hear at different points in their career, right? And so, I wanted to engage, obviously C-SED is talking to a lot of different departments, so I wanted to use the same terminology that C-SED was doing."

Notably, the ability to tailor SET content for particular contexts was also a draw for many instructors. Both the INTRO faculty interviewed and the lead CAPSTONE instructor described working closely with C-SED staff to adapt existing SET materials for their own course needs. One instructor described working closely with staff as she adapted her course for the 2020 academic year, expressing her appreciation for being able to customize lessons for her course, explaining: "I like things to be the way I want it to be. So I asked them to share what they were going to do, and then we iterated back and forth for clarity and to emphasize the things that I thought was really important." For many instructors, the ability to tailor content in this way was a significant factor in their choice to use SET.

SET modules are typically offered in a hybrid format, with both self-paced online learning and facilitator-led discussion and feedback sessions. This model was employed in most INTRO course sessions utilizing SET content, with instructors inviting trained C-SED facilitators to work with their students. Due to the shift to online learning as a result of COVID-19, all facilitation in the 2020 year was virtual, with most INTRO instructors opting for synchronous virtual sessions. Instructors perceived this facilitation as a key benefit, explaining that bringing in outside instructors seemed to reinforce the lessons' importance for students. As one stated, her students "enjoyed the interaction with additional people" and that "having the diversity of instructors saying 'hey, not only does your teacher think this is important, but we think it's important and we're going to help facilitate this' – kind of that reinforcement is helpful."

In CAPSTONE, students received feedback on their application tasks and reflections as an adaptation of the coaching component of the foundational learning block structure and there was not any real-time interaction around the SET modules. Students completed the seven modules online as separate "courses" on the university's Canvas site. Many students appreciated the flexibility offered by being able to complete the modules at their "own pace," rather than needing to be present at a designated lecture time. The modules were particularly appealing to most students when contrasted to pre-recorded lectures they had for other classes as large lecture courses were moved to virtual instruction for the 2020–2021 academic year. One student explained "I vastly preferred the learning blocks compared to lecture recordings that didn't make any sense to me." However, some students expressed a preference for real-time instruction or for an opportunity to engage with instructors or fellow students around SET content. For example, one student explained:

> "I think still the guidance of a professor would have been nice for those very important steps. Especially I think for our project because it was so open-ended just to begin with [. . .] It would have been helpful I think to have those lectures be a more discussion format rather than an asynchronous, like you read this thing and then now you have to apply it to your project."

For these students who desire more instructor or peer interaction, the typical hybrid learning block structure may be more appealing. Another common suggestion from students enrolled in CAPSTONE related to the delivery mode of the blocks was to consolidate the distinct blocks (listed as separate courses on the Canvas platform) into a common site for easier reference. As one student explained:

> "Just looking at Canvas and having, what was it, six or seven learning blocks, all of their own course, that made organization for Canvas really difficult. Having to dig for all those, finding the right one, and having to look at a different class in Canvas to figure out which one I needed to do. I think that could have been implemented a lot better."

Finally, a key purpose of the SET modules is to facilitate instruction in socially engaged design practices without requiring extensive training or demands of the instructor. As a result, instructors teaching courses in which SET content was used varied substantially in the degree of their familiarity with SET content and socially engaged design principles more generally. This variability was especially the case for CAPSTONE instructors, many of whom did not purposefully seek out SET in their courses, but were rather teaching sections of a larger course in which SET modules made up the common content across sections. While instructors consistently agreed that the SET required minimal demands on their time to implement, their prior knowledge shaped how they integrated the potentially stand-alone SET module content into their course sections. For some instructors with expertise in one or more topics covered in SET, they described an adjustment from their previous coverage of SET topics. One such instructor explained that while he would prefer to teach topics in his area of expertise, he appreciated that the blocks provided a common baseline of understanding for students even if instructor expertise across the topics varied. For this reason, he supported the use of the blocks explaining, "nobody's going to be an expert really in all the blocks." The majority of instructors who utilized the SET learning blocks had less experience in socially engaged design topics and expressed a preference for structure and guidance around the lessons. For instance, an INTRO instructor who had utilized SET content for several terms explained that she still preferred C-SED facilitators to lead the discussions, explaining "I'm not confident I would deliver the intended content the way it's supposed to be delivered. [. . .] I'd rather keep it with the C-SED experts for numerous reasons." In CAPSTONE, several instructors expressed uncertainty or hesitance about if and how they might make connections between SET content and the projects students were working on in their particular course section. As one instructor explained: "the real sort of incorporation of [SET content] relied on the instructors to actually go and look at the blocks and understand what we were asking students to do. I would say that was with varying success." Several instructors suggested that the SET include instructor training materials with suggestions on how they as instructors might better integrate SET topics into their existing courses. Other instructors suggested the SET include a written guide or template with scripts or discussion questions.

5. Discussion and Implications

Our findings point to key ways in which the SET may be improved or adapted to best meet the needs of different courses as well as broader implications for those trying to implement socially engaged content within engineering courses. Our focus on the experiences of students and faculty early adopters of the SET is informed by literature suggesting that effective change is rooted in deep contextual understanding [24, 31]. As research suggests, understanding any initial challenges or resistance may be an opportunity to improve upon the original design of a particular educational approach to better meet the needs of relevant stakeholders [29, 30], and we aim to continue to refine SET materials and structures based on feedback. Most immediately, our team is working closely with C-SED staff to consider how the SET may be improved based on the perspectives of faculty and students shared in this study. For example, in response to student feedback about the SET format of separate virtual modules in CAPSTONE, the CAPSTONE instructor has already combined all seven SET learning blocks into a single course site and C-SED staff are exploring additional online platform options for a better virtual interface. This change may also make it more convenient for students to easily find and reference various SET lessons later in their projects or academic careers.

Similarly, the challenges students raised about module timing and integrating the blocks into their projects have implications for when in a project cycle it would be most helpful for students to complete the SET modules. Though difficult to do in the 2020–2021 school year with the quick move to virtual instruction and a condensed semester timeline, going forward having CAPSTONE students complete the SET modules prior to their project or in coordination with their project timeline may be most effective. This may be particularly important in light of the fact that students are encountering much of the socially engaged content for the first time in their academic careers.

Given the challenges associated with curricular change and the importance of instructor buy-in [23–25, 28], a key goal of our study was to understand factors that drive adoption of the SET and minimize time and effort barriers for instructors. One encouraging indication of the potential for SET's adoption more widely was agreement among the faculty and students we interviewed that training in socially engaged engineering was needed. Prior research suggests that STEM curricular change is more likely to happen when there is agreement about curricular goals among a cross-section of instructors [34]. In addition to its alignment with course goals, another factor seemingly driving SET adoption was the relatively minimal effort required on instructors' part to implement the SET in their courses. Research describes time constraints and instructional challenges to be the most widely reported barriers to instructional change among STEM faculty [24].

The SET content library includes a range of materials at different levels of depth and in different formats, offering the potential for customization while still ensuring students are exposed to key principles of socially engaged engineering. Many faculty noted the appeal of this potential for customization, which raises interesting questions for the future scalability of the SET. It would require significant staffing increases to tailor SET content for each new course. As the content library grows, it is possible that instructors may have a wide variety of formats or lessons of varying depth on particular topics to select from, allowing them to find an existing format or focus that best fits their needs. C-SED is currently exploring educational technologies to make their content library more accessible for these purposes. Another possibility is that instead of relying exclusively on individualized tailoring of SET content on an instructor-by-instructor basis, we could develop guidelines or a template for instructors hoping to more specifically situate materials within their course format and focus, with continued consultation available when instructors have questions. In the case of CAPSTONE, the written project guidelines were updated to more explicitly link the learning blocks to the student course projects. As suggested by several faculty in this study, we may also offer live or recorded trainings for faculty to consider how they might best tailor SET content to their needs or identify strategic ways to bridge learning block lessons with the specific technical focus of their course. As we explore expanding SET offerings to other courses and institutions, such trainings or guides may offer greater scalability and less instructor effort than individual collaboration with or instruction by C-SED staff.

The lessons learned from our study of the experiences of faculty who were early adopters of the SET and of their students have broader implications for those interested in advancing other models of integrating socially engaged engineering training within their curriculum. Engineers' abilities to account for the social and contextual dimensions of the problems they encounter is increasingly recognized as a critical skill [8–10], but one with which many engineering students still struggle [18, 19]. While some faculty may recognize the need for additional training related to socially engaged dimensions of engineering, there are often a number of individual and systemic barriers to curricular change in STEM fields [23–25]. Based on our findings in this study and lessons from existing research on ways to support curricular change [24, 31, 33, 34], we encourage those interested in advancing their own efforts to enact curricular change to engage with a range of faculty to understand the particular college and departmental context shaping their experiences, collaboratively explore how a proposed curricular change may compliment their own course goals, and consider how such changes may be made accessible to them in terms of the time and prior knowledge required and support provided to implement any changes. As is the case in our own work with the SET, any change efforts are likely to necessarily be an iterative process informed by student and faculty input.

6. Conclusion

This study explored faculty and student experiences with the Social Engagement Toolkit (SET), an educational resource intended to reduce barriers for instructors to integrate lessons in socially engaged engineering practices within their courses. Interviews with early adopter faculty and their students provided insight into faculty motivations for using the SET and perceptions about the strengths and challenges of SET. We found that ease of implementation, alignment with course goals, and the ability to tailor materials for their course were key factors driving these instructors' decisions to employ SET modules in their courses. Some instructors expressed a desire for more resources or training on how they might independently adapt or bridge SET content to their particular course content. While many students appreciated the flexibility offered by the learning block structure, some students who completed the entirely virtual adaptation of the (typically hybrid) learning blocks expressed a desire for more instructor or peer interaction around the blocks. Students often explained that completing SET modules was their first substantial exposure to socially engaged engineering topics in their academic careers. Students in a senior design course varied in the extent to which they reported being able to apply SET principles in their course projects, though the majority felt the lessons were relevant to their future academic or professional engineering work. Findings from this study of early adopters have implications for future iterations of the SET and the adoption of the SET or other efforts to integrate socially engaged engineering training in other courses or at other institutions.

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Appendix

Example Application Task from the Social Context Assessment Learning Block

This application task for this block will walk you through how to evaluate a technology according to the second two necessary conditions for sustainability. Please write up your responses and click to the next page to submit. Note that there are three total parts to complete.

The technology:
Electric bikes (e-bikes) have a battery-powered electric motor to aid pedaling, making biking more accessible to commuters who are older, exercise-averse, or traveling with cargo. While the bike itself is a zero-emission vehicle, battery recharge generates upstream emissions dependent on the source of power generation.

Part I
Create a stakeholder map that lists primary, secondary, and tertiary stakeholders for the e-bike. Make sure to include at least two individuals, groups, or organizations from each of the six ecosystem categories. Color code/tag each individual, group, or organization according to the following key: Resource Providers (RP), Supporters & Beneficiaries of the Status Quo (SB), Complementary Organizations and Allies (CA), Beneficiaries and Customers (BC), Opponents and Problem Makers (OP), and Affected or Influential Bystanders (AB).

You may use the attached Powerpoint template Download attached Powerpoint template to complete this part. After you complete your stakeholder map, answer the following questions:

- Were there any individuals, groups, or organizations in your stakeholder map who might fulfill multiple ecosystem roles? In what scenarios might stakeholders fulfill multiple roles and/or switch between roles?
- Are the primary stakeholders you identified also the main decision-makers regarding the production of e-bikes? If not, who are the main decision-makers? What challenges might emerge in situations where the primary stakeholders are not the main decision-makers?

Part II
Calculate the life cycle cost associated with manufacturing and owning an e-bike and a regular bike over a 10-year period. Your life cycle cost for each bike should sum together the following costs, some of which may be calculated through CES (building on earlier work from the Environmental Context Assessment application task), and some of which may require other research.

- Year 1 material, manufacturing, and transport costs. These costs can be estimated using the cost analysis function of the CES eco-audit tool (see the "CES Eco-audit instructions Download CES Eco-audit instructions " file). (Note: the package dimensions of both bikes are 4ft by 2.5ft by 6ft).
- Initial acquisition cost, or the purchase price of the technology. Assume that the acquisition cost for the e-bike is \$1300 and the for the mountain bike is \$300.
- Electricity use costs over the entire use phase. The use phase cost in the CES cost analysis sums across all years of use. Calculate the average yearly operating costs and then convert to net present value (NPV) assuming a discount rate of 4%.
- Environmental costs over entire use phase. Convert the average yearly environmental cost provided in the CES cost analysis to NPV (discount rate 4%).
- Maintenance costs over the entire use phase. Assume that the annual maintenance cost for each bike is 5% of the initial acquisition cost and convert to NPV (discount rate 4%).
- Disposal costs at end of life. You can treat the disposal cost from the CES cost analysis as a future cost that you convert to NPV (discount rate 4%).

Answer the following questions:

- Which type of bike was predicted to have lower life cycle cost overall? (Show your work, using either an excel table or calculating by hand)
- Which process(es) contributed most to the life cycle cost for each bike? Which process(es) contributed least? Why do you think that was?
- How might your life cycle cost calculation change if you adopted a higher discount rate when calculating net present value? What about a lower discount rate? Would the same bike still have the lower cost in each of these scenarios?

Part III
Based on your analysis above, answer the following questions:

- What is the likelihood that e-bikes will be adopted and self-sustaining in the market? Specifically, who is the primary market, and will they be able to afford e-bikes compared to other alternatives?
- What is the likelihood that e-bikes will become so economically successful that planetary or social systems will be worse off?
- Which individuals, groups, or organizations are likely to benefit most from the production of e-bikes? Which individuals, groups, or organizations are most likely to bear the costs associated with the production of e-bikes?
- Based on your answers to the above questions (and your work from the Environmental Context Assessment block), are e-bikes likely to be sustainable?

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