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Assessing Socially Engaged Engineering Training on Students' Problem Solving: The Development of a Scenario-based Assessment Approach

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Contemporary engineers are called upon to solve problems within an increasingly complex world. In order to adequately address modern engineering problems, engineers must generate solutions that attend to stakeholders, context, and impacts across scales, in addition to being technically sound [1],[2]. Thus, engineering is fundamentally a technical and social discipline [3], [4], [5]. *Socially engaged engineering* skills include those needed to gather environmental, economic and stakeholder information and use it, combined with an understanding of personal/professional identity and team dynamics, to holistically serve clients and society through engineering work [16]. Socially engaged engineering skills are vital for the future of engineering and they are recognized as just as necessary as traditional technical skills of the field [6], [7], [8]. Despite the importance of socially engaged engineering skills, they have largely been underemphasized or entirely missing from engineering education coursework [9],[10].

There are several barriers to better integration of socially engaged engineering skills into engineering curricula. Instructors may resist changes to curricula for both individual and structural reasons [11], [12], [13]. For example, instructors may have been trained to emphasize technical and mathematical problem-solving techniques over decision-making strategies and analyses that determine how appropriate (if at all) a particular solution is for a given context. This training combined with pedagogical preferences and values, a potential limited understanding of or experience with alternative teaching methods, and/or discomfort in facilitating content outside their area of technical expertise all serve to reinforce resistance to curricular change. Academic culture emphasizes the autonomy of instructors and instructors across disciplines tend to be protective both of their course content and discretionary time [14]. Prior research suggests that instructors of the "hard sciences" may be particularly resistant to change [15]. While some instructors are starting to acknowledge the gap in engineering students' skill sets between knowing how to solve a problem and knowing whether a solution fits a particular application, structural factors compound the barriers to curricula change. In order to incentivize curricular change, institutions must provide adequate resources, time, training, and support around efforts to develop new material.

Instructional interventions to better train engineering students in socially engaged engineering skills must address instructors' prior knowledge and comfort with new material, as well as structural conditions such as instructor autonomy, time provided for training and curriculum development, and incentives for developing and integrating new course materials. To address these challenges, the Center for Socially Engaged Design (C-SED) at the University of Michigan developed a collection of educational and training resources called the *Social Engagement Toolkit* (SET). This Toolkit uses a hybrid learning approach designed to support instructors without expertise in socially engaged engineering. Instructors select and assign on-demand lessons for their student on a variety of training topics to develop socially engaged engineering skills.

For any new educational intervention, it is critical to understand the uptake and efficacy of that approach. To this end, our team is engaged in research on the implementation and impact of the SET across a number of engineering courses. One dimension of our research includes evaluating how students' thinking about engineering problems changes after participating in courses that use the SET. To gain a holistic understanding of the ways students' thinking changes over the course of a semester, we developed a scenario-based study in which we interview students at the beginning and end of a course that employs the SET. The present paper details our process of developing this scenario-based study, including our process for identifying appropriate scenarios to address our research goals and the lessons learned. In addition, we conducted pilot interviews with students experienced in socially engaged design skills in order to explore the range of responses elicited by our scenarios. We detail preliminary findings from these interviews to demonstrate the efficacy of our method for eliciting students' thinking about a range of socially engaged design topics and to illustrate how students experienced in these areas may respond to our scenarios.

Background

Instructional Intervention Studied: C-SED Social Engagement Toolkit

C-SED was founded in 2015 with the intent of providing expertise, curricular and co-curricular workshops, and a physical space for students, staff, and instructors to learn and develop socially engaged engineering skills [16]. The center offers content, training, and support through several mediums to flexibly support a variety of users (students and instructors) in both curricular and co-curricular contexts. A key resource developed by C-SED is the Social Engagement Toolkit (SET), a content library with customizable lessons for a range of uses. One aspect of the SET that will be used in the courses we are investigating with the scenario-based interviews are adaptations of hybrid learning blocks, a resource developed by C-SED to provide an independent pathway for student learning [17]; Adaptations of the materials for courses usually consist of both virtual, on-demand content and personalized feedback or synchronous expert facilitation on a particular topic. Instructors or student organization leaders can select resources on one or more socially engaged topics appropriate for their context from the SET content library.

The SET covers a variety of topics including how to conduct interviews, generate ideas, and reflexively handle power differences, and ultimately aims to support undergraduate engineers' skill development so that they are able to develop both technically sound and socially appropriate solutions relative to the solutions' context of use. With this learning model students can receive holistic instruction without engineering instructors having to be skilled in every aspect of socially engaged engineering. The SET draws on expertise and experience from a multitude of contexts and combines it in the form of examples, practices problems, and more to facilitate student learning.

Students' Socially-Engaged Engineering Skills

A national study of engineering education found that, though instructors and administrators widely agreed that engineering programs needed to prepare students to consider all relevant factors when solving problems, both groups reported that their programs and courses placed only slight to moderate emphasis on understanding how engineering solutions could be shaped by social, environmental, political, and cultural contexts or considerations. They reported even less curricular emphasis on ethical considerations and on asking students to examine their personal beliefs and values and how those influence their decision making [18]. In some contexts, engineering students may appreciate the importance of various contextual information—e.g., cultural, political, environmental—however, they frequently struggle to integrate this information into their practice [19]. In addition, engineering students do not have a strong understanding of their biases, lenses, or norms [19]. These shortcomings are, in part, the result of limited exposure students have to the social sciences and the humanities during formal engineering education. In addition, the prioritization of technical expertise and technical outcomes and the treatment of non-STEM experts as representatives of entire contexts [20] (e.g., consulting an economics expert equates to understanding all economic context relevant to the problem/solution) implicitly devalues practices and experiences that would support the development of socially engaged engineering skills. Specific, intentional training is needed to overcome engineering students' insufficient gathering and use of contextual information because without the ability to determine the "real problem" the creation of successful solutions is unlikely [21],[22].

Use of Scenarios to Study Engineering and Design

Studying the skills and behaviors of engineers and designers has been a focus for design research for nearly 50 years, resulting in varied protocols, study settings and analysis approaches [23]. Problem scenarios combined with open-ended questions have been used in engineering education to assess a variety of skills, including socio-technical thinking [24], systems thinking [25], engineering design broadly [26], considering context during the problem-scoping portion of engineering design [27] and considering broader impacts of design decisions [28].

Scenario-based methods offer a number of benefits regarding the type of information collected. Mazzurco and Daniel [24] argued that authenticity is a key characteristic of scenarios because they approximate real-world problem solving conditions. Open-ended problem-solving scenarios have also been used as an assessment tool to investigate how students articulate and use their engineering skills [28]. Overall, scenario-based studies provide an opportunity to explore students' thinking as they solve engineering design problems.

Researchers who have used scenario-based methods offer several cautions about important considerations when developing such a study. First, it is important to remember that the way a problem statement is written impacts the way designers determine an appropriate solution; the information in a scenario and how it is framed shapes how designers will respond [29], [30]. In addition, the method in which the participants interact with the scenario has the possibility of becoming a barrier to communicating ideas. In a study conducted by Kokotovich [31], students generated mind maps to communicate their thinking. This method provided an opportunity for deep investigation; however it required the students to have existing knowledge of how to create a mind map. In a review of empirical design studies, Dinar et al. [32] noted several considerations for researchers developing study materials, including the range of participants' backgrounds, how participation in the study may shape students' thinking, and the importance of developing a scenario with an appropriate degree of difficulty given the domain and extent of participants' experience. Each of these examples highlight important considerations to remember while developing a scenario-based study. In the following section, we address how our research team approached scenario development to ensure our materials were appropriate and well-suited to our needs.

Scenario Development Process

Study Goals and Study Design Considerations

Our development of the scenario study design and selection of particular scenarios was guided by our study goals, prior literature on scenario-based studies, and work on assessments of design more broadly, along with the emphases of C-SED's SET. Prior to selecting particular scenarios, our team made several design decisions based on our research goals. Prior research (e.g. [17], [33]-[37]) examined student learning as a result of engagement in a C-SED learning block training on a single topic. Our goal for the present study was to examine change in students' socially engaged engineering skills in a more holistic manner over the course of a semester. For this reason, we elected to use a pre/post study design in which students will be interviewed at the beginning and end of a semester-long course. The SET offers customizable trainings (through learning blocks and/or guided facilitation) on a number of topics, so it was also important that our study design allowed us to explore students' evolving thinking broadly, not their learning related to a single topic. Further, we wanted to be able to capture the range of considerations identified by students when thinking about a problem, including (but not exclusively) socially engaged engineering skills. We chose a scenario-based protocol given the variety of engineering education scenario-based studies and their documented ability to elicit participants' articulation of their thinking related to realistic engineering problems. Further, using an open-ended scenario study allows researchers to understand what is salient to students based on their own words in response to the problem.

Another consideration that guided our study design was assessment within a relatively short time in a single session. While some think-aloud scenario studies (e.g. [26], [38]) provide added information in a session and can take several hours to complete, we hoped to develop an interview protocol that took approximately an hour and was not dependent on interactive information-seeking. Our study protocol did not offer any opportunities to seek additional information about the context of the scenario problem. Instead, we opted for a study design in which we first presented brief open-ended problem statements to elicit participants' initial thoughts and then presented an example solution developed by others and asked participants to talk us through their critiques and additional thoughts in response to the solution. This design choice was intended to help us avoid the possibility that participants were reacting merely to details contained in our problem framing (consistent with literature on the influence of problem framing and the potential fixation on aspects of problem framing outlined [29], [30]), while still providing something common for all participants to react to. Relatedly, we decided to present students two problem/solution sets in both the pre interview at the beginning of the semester and the post interview at the end of semester, as well as randomizing which interview the scenarios would be presented and the order in which they are presented (ensuring each student sees different scenarios in each interview).

In our study protocol we first present students with a brief open-ended problem statement related to the first scenario and ask a series of questions intended to elicit their initial reactions. Examples of questions in this first portion of the interview include:

- What strikes you as the most critical things to address in this problem?
- What sort of information would you want to gather about this problem?
- What are some potential pitfalls, or things that might go wrong while addressing this problem?
- How would you know if a solution to this problem was effective?

Next, we present an example solution (presented in the form of a student project poster) for the same problem and ask participants to reflect on the solution and offer critiques. Example questions in this portion of the interview include:

- What are your first impressions about how the team addressed this problem?
- What is something you think team did well with this solution?
- What could the team have done differently?
- Hypothetically, if the solution presented was ultimately unsuccessful, what might you assume were the key issues?

After completing discussion of the first scenario, we then repeat the same steps for a second scenario. Within the context of this larger study design, we focus here on our process to identify and select appropriate scenarios for our study.

Scenario Selection Criteria and Process

Our process for identifying appropriate scenario topics was guided by the following core criteria:

1) Topic lends itself to an easily developed, short scenario;
2) Topic does not require prior in-depth content knowledge, and it is accessible to undergraduates at a range of experience levels; and
3) Contextual information is available for the topic, but it is not the only driving factor in problem definition and solution formulation processes.

The first criterion reflects our study goals of relative brevity and simplicity. This consideration was particularly important due to the pre/post nature of our study, requiring students to participate in two sessions in a single semester. The second criterion reflects the need to have appropriate scenarios for students with different levels of experience and different engineering disciplines, consistent with recommendations from literature (e.g., [32], [31]). The third criterion allows students to consider social and contextual aspects of a problem, but it is sufficiently broad to plausibly elicit students' thinking on a wide range of engineering considerations, without being excessively leading towards social and contextual aspects. Similar principles guided our thinking about the example solutions provided for student critique. The provided solutions had to allow for open-ended critique on a number of dimensions and be easily understood by students without specific technical expertise.

These selection criteria served as the foundation for subsequent decisions about our scenario design and selection. To improve reliable measurement and meet our first criterion related to brevity, we standardized the presentation of the problems and examples solutions. We present each scenario in a standardized PowerPoint presentation, and the problem statements are written using a modified Design Problem Framework [39]. We modified the "Context, Goal, and Needs" framework to "Background, Goal, Requirements, a change intended to reflect the vocabulary common in engineering courses. The example solutions were also presented on a single PowerPoint slide in a standardized format, and the content was drawn from examples of student posters presenting engineering projects. Each solution poster included three sections: Problem Statement, Final Product Description, and Testing and Evaluation.

Our second and third criteria shaped decisions about the domain and emphasis of the problems and solutions selected. Given accessibility concerns, we avoided problems using extremely specialized technical or contextual information. For example, military device problems were not widely accessible to students without a military background. We similarly elected to avoid scenarios with an explicit international development focus because students may have limited familiarity with particular international contexts compared to domestic contexts. These criteria related to allowing for a consideration of familiar contextual dimensions. We selected scenarios in two domains—medical or biomechanical devices, and energy and environmental problems—to vary the contextual and technical aspects presented in the scenario problems.

With our selection criteria in mind, we began collecting a range of potential scenarios with existing example solutions. We looked to product recalls, commercial flops, and student design projects in our initial round of searching. Based on this initial search we realized that product recall examples were typically due to a very specific technical failure, preventing a more open-ended exploration of the problem and solution. Similarly, commercial product "flops" were potentially familiar to students, close-ended, and difficult to collect sufficient contextual elements related to the failure. Thus, we elected to focus on student design projects. Student design projects were collected from publicly available engineering capstone design course websites, which typically provided ample information about projects. The capstone websites were located through Google searches of university engineering capstone design programs from around the United States.

Our initial search identified 13 student design projects fitting our criteria, covering a range of domains and including a diverse set of contextual elements. Three of these were discarded by our team because they did not include enough information regarding either the problem or the solution, and one uniquely targeted a sociodemographic subgroup. The nine remaining projects were standardized as described above and shared with pilot interview students. In this initial round of feedback, student responses varied greatly. Some resulted in thorough investigations of the problem and solution when the scenario context directly related to the participant's experiences or interests, but others elicited narrow, uncertain and uninformed comments. This dichotomy suggested that many of the projects did not meet the second and third selection criteria as defined above.

This first round of feedback provided several important insights for our scenario selection and study design. First, the feedback indicated that only three of the nine projects were suitable for the full study. Second, our protocol took an average of 23 minutes per scenario, allowing completion of two in a one-hour interview and meeting our criterion of brevity. With three viable problem/solution sets, we engaged in a second round of scenario collection and feedback to gather more possibilities.

For this second round of scenario identification, particular care was taken to collect projects that would create a balanced set of both medical or biomechanical focused projects and energy and environmental projects. As mentioned above, these domains were identified as being well-suited to potentially eliciting a range of technical and contextual considerations. The three projects that had survived the initial round of feedback were all medically/biomechanically focused projects, so we narrowed our search to mainly energy and environmental projects. We conducted an additional review of available student design projects to identify four additional energy and environmental focused scenarios to add to the existing three problems for a second round of feedback.

Our preliminary round of pilot feedback included student engineers without training in socially engaged engineering. In our second round of pilot interviews, we presented our selected problem and solution sets to graduate students with substantial knowledge of socially engaged engineering principles. We recruited these students to help us explore potential socially engaged dimensions in the test scenarios. In this phase, six graduate engineers participated. Demographic information is omitted here to protect anonymity. Each interview lasted between 1-2 hours, and each participant was presented with 2-6 projects, averaging 1.5 hours and 3 projects per participant. Each project was presented in the prescribed task format of the problem statement first, and then the solution presentation. The purpose of these interviews was twofold: 1) to test our selected scenarios to ensure they elicited responses related to a range of potential engineering considerations, and 2) to inform our understanding of what experienced engineers might address in the scenarios, particularly social or contextual dimensions. These interviews ultimately enabled us to identify six scenarios meeting our selection criteria to move forward with in our full study.

Preliminary Findings

As described above, a key part of our team's process for selecting, evaluating, and understanding how students might respond to potential scenarios included several rounds of pilot interviews. One of these interview rounds was with graduate students who were well-versed in principles of socially engaged engineering and design. In addition to allowing us to assess how the different scenarios worked with respect to our selection criteria, these interviews also provided insight into how students with a greater awareness of socially engaged engineering skills consider engineering problems and solutions. In this section, we describe three of these students' responses to different problem and solution scenario sets. The summaries below are not intended to be a comprehensive accounting for all the dimensions identified by these participants, but rather highlight a range of key considerations emerging in the second pilot study.

Example 1: Participant A's Response to Underwater Mat Scenario

The first example comes from Participant A's response to a project in the energy and environmental domain. In this project, a west coast company was developing a way to generate electricity from the bacteria in the ocean. The design task described was to create a device that would unroll a mat covered in energy generating devices onto the ocean floor.

When initially presented with the problem statement, the Participant A's reaction focused on the disruption that would potentially be caused by implementing such a device to generate energy, especially in comparison to existing forms of renewable energy. They began with a high level approach, stating "I would start big like what is that big context" and continued by questioning who might be supportive of such a device, what might motivate its creation, and the potential stakeholders involved in the problem. They argued that, in this context, the environment should be considered as a stakeholder. In addition, they raised issues related to device accountability and ownership of a potential solution, especially given potentially ambiguous jurisdiction of the ocean. Participant A's final reflections on the problem statement focused on the hypothetical design team that would solve the problem and how the types of experiences the team have had may inform decisions regarding the project.

When presented with an example solution, Participant A raised additional questions about the team's motivation for making the decisions they did. They paid particular attention to how people and the community were involved in the decision making processes and how the needs and the constraints of the community were considered in the team's design. Throughout the solution critique portion of the interview, Participant A continued to reflect on the environmental impact of the device, including the environmental impacts of material selection, material sourcing, and the supply chain. Their response reflected a particular concern with the sustainability of the device, related to its longevity, maintenance, and what happens when it is retired. Finally, Participant A questioned the team's process for developing the example solution, wondering if the team was purely fixated on satisfying the technical requirements of the project or if they allowed themselves to focus on the trade-offs within the expansive context of the problem and solution spaces.

Example 2: Participant B's Response to Spinal Decompression Device Scenario

The second example comes from Participant B, another graduate student experienced in socially engaged engineering skills, in response to a project in our medical/biomechanical domain related to spinal decompression. The framing for this project highlighted how 31 million Americans experience back pain, which could be attributed to slipped spinal discs. The design task was to create a device that would enable people to decompress their spine and find relief from the painful slipped disc.

In the first portion of the interview, when presented with only the problem statement, Participant B focused extensively on making sense of the problem and its context. Their initial reaction was skepticism that 31 million cases of back pain could be attributed to causes that could be resolved by spinal decompression. They posited that such a blanket claim suggested the project motivation was driven by making money, as opposed to addressing an actual health problem. They expressed a desire to gain a deeper understanding of the problem, stating:

> **"**Learn a lot about spinal decompression, maybe get myself a spinal decompression procedure done. That's what I'd want to know… how it's diagnosed, the whole medical industry system around spinal decompression. So diagnoses, how long are people in pain before they get diagnosed if they ever get diagnosed, how many people don't get diagnosed, how do they get treated, how long does it usually take in different scenarios, how much they pay for it what is covered by insurance, what isn't, how sure people are of the diagnosis of these. I know lower back pain can be very hard to diagnose… I think just some more medical stuff and then some more like contextual stuff around like the medical industry."

Participant B continued by further probing the problem statement, explaining that they would want to talk to people who need or have had spinal decompression treatment in order to understand how it is currently done, what the current issues are, and where the gap is.

Reflecting on the example solution, Participant B exclaimed, "That is so impersonal - put the user back into this engineering solution, please." They questioned or critiqued a number of aspects of the presented solution related to user comfort, user safety, and user needs. In addition, they reflected on the limited information regarding the team's process of evaluating their design provided on the poster presentation. Additional questions about the design team's process included wondering if alternative solutions were considered and if the team had diverged before they converged upon the chosen solution. Although much of Participant B's remarks centered on the importance of considering the user in the solution, they did remark that the team's final product, which included a fully built device with an integrated stepper motor, was impressive. However, their concluding comments reflected a desire for more information "linking [the solution] back to the requirements and the human aspect."

Example 3: Participant C's Response to Teen Mobility Scooter Scenario

The final example comes from Participant C's response to another scenario in our medical/biomechanical device category. This project description stated that a teenage student at a particular school needed a personal mobility device unlike any other. The design task was to create a cool scooter for the student.

In reflecting on this scenario, Participant C connected the project to a prior experience they had working on an engineering capstone design project and framed much of their discussion in this context. When presented with the problem statement, Participant C noted a need to learn more about the student and why they require mobility assistance, stressing the importance of understanding the students' day to day life. They explained:

> "A lot of questions I would want to ask is how old is this student? Will they like outgrow whatever you make for them? Are they a young child or are they a teenager? Should the product get any bigger? What kind of mobility assistance [do] they need? What [do] they need in their everyday lives? What are their everyday problems or things that have helped that could make it easier?"

Because the Participant C had substantial experience with projects similar to this scenario, they named many aspects of the problem that would be important to consider. These included investigation on how the student interacts with the world, how the world around the student is set up, who is in the student's support system, specifics regarding Americans with Disabilities Act (ADA) regulations, and how the requirements connect back to the student. They also raised questions regarding the assumptions the designers may have brought to the project or individual the solution was intended for. Several noteworthy questions raised by the Participant C included what dreams the teenage student has in regard to their mobility, how might the designers make the solution engaging for this student, and finally, how would the device affect the confidence of the student.

When presented with an example solution, Participant C again raised comments related to a number of nuanced aspects of the problem and solution. In addition, they also explained they wanted to know more about how the team tested their device and whether it was conducted in a way that accurately reflected the environment in which the student would use the scooter. Relatedly, they also noted considerations related to the evaluation process and how the user's feedback was integrated into the design in order to inform iteration. They questioned:

> "How they're engaging with people you know, are they working with or for them? To them? Not even working with people, just making something and being like 'hi let's use it on the student', which is very dehumanizing… Are you thinking critically about what you're doing with the feedback that you're getting? Are you reflecting on your decisions and why?"

The interview with Participant C reflected an emphasis on the importance of ensuring the product or its design process is not dehumanizing to potential users, particularly in light of the fact that a specific user's needs motivated the project.

Discussion and Directions for Future Work

As the above examples highlight, our interviews with graduate students experienced in principles of socially engaged engineering elicited a wide range of factors considered in response to our study scenarios. As might be expected of students with this type of experience, our participants demonstrated consideration of a variety of social and contextual dimensions of the different problems. These participants also reflected on some more explicitly technical dimensions of the scenarios, though the focus in these interviews was to gain insight into students' thinking related to socially engaged aspects of engineering.

Several themes arose from the interview data. One notable theme was the way these experienced students spoke about stakeholders both broadly and deeply. In discussing stakeholders, several participants noted the larger communities that would be affected by the problem beyond an immediate client or user. More importantly, they discussed a number of questions or strategies they would draw on to ensure a deep understanding of the stakeholder needs and motivations, as well as how to integrate a consideration of stakeholders throughout the design process. The participants also raised a number of contextual considerations including regulatory and political bodies, the immediate environment in which designs may be deployed, and environmental impact such as the sustainability of designs and the sourcing of materials used. Beyond gathering an understanding of context and stakeholders, several participants pushed on the framing of the original problem statements, wanting to understand what truly motivated the problem and why a particular requirement or solution type was indicated. Finally, they spoke extensively on the design process itself, raising questions about how teams who developed the example solutions may have gathered information, iterated, and evaluated their designs. The breadth and depth evident in these graduate student participants' considerations of human or contextual aspects of engineering showed clear differences from the understanding typical for engineering students [18], [19].

Findings from our initial pilot data inform our future work on this project in several key ways. First, given participants' feedback on the scenarios and the wide range of considerations identified by the graduate students experienced in socially engaged engineering and design, we were able to identify six scenarios that were appropriate to move forward with in our wider data collection efforts. Their responses help us better understand the possible range of factors students might identify for each problem. These responses will also help us evaluate future responses, from presumably less experienced undergraduate students, by providing examples of how engineers who are experienced in socially engaged engineering respond. Many of the considerations named by our pilot participants reflect key emphases of the C-SED Social Engagement Toolkit. As we move forward with our study and conduct interviews at the beginning and end of each semester, we hope to understand how students demonstrate growth in any of the socially engaged engineering skills integrated in their courses that use the SET. In our full studies, we hope to develop a scoring guide grounded in our prior work, current data, and inductive analysis of undergraduate student responses to both categorize factors considered and differentiate *how* students think about and discuss them.

Our multi-phase process of developing and selecting scenarios for our study may offer some insight for other researchers hoping to employ scenario designs in their assessment studies. One step important to the scenario development was identifying guiding criteria for selection to reflect the specific goals of our study. We revisited these criteria throughout our process as we considered how to best operationalize them in our study design. The multiple rounds of iteration and feedback also proved to be essential. Rather than waiting to get feedback or test our scenarios at a later stage, we sought feedback on problem/solution scenarios as a way to explore potential types of solutions and develop our protocol, iterating substantially based on this external feedback. We also thought extensively about how to ensure the scenarios were accessible to a wide range of students and yet also felt authentic to their training experiences, considerations identified as critical by others using scenario research (e.g. [32], [24]). Using real-world student design projects provided this authenticity, and pilot participants remarked that the types of scenarios we ultimately selected felt familiar and accessible. Investing in scenario development was time-consuming and involved more than one round of pilot testing; however, the results suggest this process has produced a sound measurement task to elicit students' use of social and technical factors in engineering design.

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