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RFE: Using Scenario-Based Design Tasks to Explore Sociotechnical Thinking in Engineering Students and Professionals

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Introduction and Background

Sociotechnical thinking, for us, means the ability to consider and integrate technical and non-technical factors alongside each other in engineering contexts. An example of sociotechnical thinking might involve the consideration of the strength and performance of an engineering material for a given application alongside considerations of the carbon footprint or human impacts of acquiring and processing those materials. Sociotechnical thinking is critical in engineering problem solving, as engineering solutions have impacts in both technical and non-technical areas (e.g., societal, environmental, global). As a result, it is critical that engineering educators develop approaches to assess or measure sociotechnical thinking.

While existing research is limited, several studies offer useful insight for how one might operationalize sociotechnical thinking in ways that can be used in research or assessment. For example, Mazzurco et al. [1] used a framework that consisted of *technology, people,* and *broader context* to evaluate participant responses to sociotechnical prompts. Burleson et al. [2] adapted a framework from Aranda Jan et al. [3], and used a framework of nine sociotechnical dimensions to analyze student interviews and design reports. Emberley and Lutz analyzed student responses to sociotechnical modules and found that students can identify a wide range of technical and non-technical factors and often do so in ways that overlap or interact in complex ways [4].

These findings highlight several important points. First, they show how sociotechnical thinking can be operationalized in research and assessment contexts. The frameworks and methods used in these studies were able to describe different kinds of sociotechnical thinking and in some cases different levels of depth of sociotechnical thinking. Another important finding is that sociotechnical thinking can be operationalized in terms of multiple interacting domains that range from technically focused to socially focused. Finally, they show that sociotechnical thinking can be identified in a wide range of artifacts including survey responses, interviews, design documents, and collaborative design activities, suggesting a wide range of ways researchers might explore sociotechnical thinking.

The purpose of this paper is to describe the development and implementation of a collaborative, scenario-based design activity intended to elicit discussion of sociotechnical dimensions of engineering problems. We outline our development process, provide an example scenario, and present preliminary findings that demonstrate the efficacy of the activity in encouraging sociotechnical discussions. These scenario-based design tasks can be used both as a research instrument for studying sociotechnical thinking and as an instructional tool to support pedagogy.

Methods

We used an iterative process to refine our selection of scenario-based design tasks from over 100 to a final three. We began by first generating a broad list of potential sociotechnical problems, using automatic item generation and human-in-the-loop techniques with AI to create a diverse set of candidate prompts. We refined this list through a combination of pilot testing and group consensus processes focused on making our prompts accessible to engineers of different experience levels, interests, and engineering knowledge generally. The following section outlines each of these refinement processes in more detail, offering a description of the process and justification for the steps taken.

First, we leveraged automatic item generation (AIG) techniques [5], [6], [7], [8] alongside human-in-the-loop frameworks [9] to create an initial list of sociotechnical prompts. We used ChatGPT (Model 4o) to generate a list of initial scenario-based design tasks. More specifically, we prompted the model with information about the nature of the study, the goals of our work, the theoretical basis for the work, the different populations we would be studying, and other relevant context as needed to increase the usefulness of the output. Author Lutz used this AIG/human-in-the-loop process in ChatGPT to iteratively generate over 100 different scenarios and prompts designed to encourage sociotechnical discussions in engineering contexts. This list was then reviewed and edited by the Author Lutz and refined into 13 scenario-based design tasks. This initial refinement from hundreds to 13 was based on clarity of the prompts, suitability for the research context, and considerations of appropriateness for both student and professional populations of engineers. The list of 13 was then shared with the larger research group for feedback, with the goal of selecting three scenarios to be used for our data collection. We considered several additional factors to develop accessible, engaging prompts that would encourage discussion of a broad range of technical and non-technical factors of engineering problems.

One key factor that helped us further refine our prompt selection was consideration of accessibility to different experience levels. Our intention was to design problems that were of a technical complexity and depth that engineers of all experience levels might find engaging (albeit in different ways). For example, some of the initial 13 prompts referred to designing robots, wearable fitness tracking devices, and automating delivery systems, which might exist in somewhat niche domains and thus might not be familiar to all participants. Instead, we focused on areas of engineering design where a wider range of participants might have had some familiarity. Another key factor that informed our final selection of prompts was the inclusion of under-incorporated sociotechnical factors in our prompts. Across Aranda-Jan's contextual factors, students and other low-experience engineering participants incorporate technological and institutional factors far more than infrastructural, industrial, economic, public health, sociocultural, and environmental contextual factors [2], [3]. We selected specific prompts and accompanying scenarios that would encourage participants to intentionally consider a wide range of technical and non-technical factors. Our final consideration in refining our sociotechnical prompts was to make sure that we had prompts that would be inclusive to a broad range of disciplines. We recruited participants from across the entire Cal Poly San Luis Obispo College of Engineering, and therefore both our student and professional participants came from a wide range of engineering disciplines. The considerations helped us refine from an initial list of thirteen to a final set of three scenario-based design tasks, each containing a central design prompt and three accompanying scenarios.

Results

The following section outlines two main outcomes of the work to date. First, we highlight the scenario-based design tasks themselves, offering a detailed example and articulating how it aligns with our selection criteria discussed above. Second, we offer some preliminary evidence that these design tasks are effective in eliciting sociotechnical discussions in groups of engineering students and professionals with wide variations in experience levels.

Scenario-Based Design Tasks

Using the AIG and piloting criteria outlined in the previous section, we selected three prompts. Our three prompts' central ideas were "designing an ergonomic public seating solution for urban spaces", "designing a wind turbine for a coastal community", and "designing a compact solar-powered street lighting system". The prompts position participants as members of a design team tasked with developing a solution to an engineering problem with sociotechnical implications. The central prompt offers information about the desired solution, provides some context, and offers suggestions for sociotechnical factors to consider throughout the activity. The prompt also offers some instructions for how to accomplish the research task. Each central prompt is then followed by three accompanying scenarios that provide more specific considerations. After the 40-minute brainstorming session, the interviewers reserved the last 10-15 minutes to shift into a retrospective group interview, allowing for the interviewers to ask additional questions to better understand participants' thought processes during the design activity.

As an example, we provide the central prompt and three accompanying scenarios we used for a prompt about a public seating solution for urban spaces (the other two are in the Appendix).

Designing an Ergonomic Public Seating Solution for Urban Spaces

You are part of a team of engineers tasked with designing an ergonomic public seating solution for urban spaces, such as parks and transit stops. The seating system should account for design criteria such as comfort, durability, and strength while also considering the sociotechnical implications of its operation, including but not limited to social, political, cultural, or environmental impacts. Your task is to brainstorm and explore different solutions to this challenge that consider both technical and non-technical factors. As a team, you will have 30 minutes to brainstorm as many different solutions as you can, using the scenarios and questions to help you develop solutions.

Scenario 1: A diverse group of users, including elderly individuals and people with disabilities, needs to use the public seating. How can the seating system be designed to accommodate different mobility levels, body types, and other human factors?

Scenario 2: The seating solution is to be installed in multiple cities with varying cultural norms and social dynamics. How can the design be adaptable to different contexts while still meeting the core requirements of comfort, durability, and accessibility?

Scenario 3: The seating solution may need to be relocated or reconfigured over time due to changes in urban planning or community needs. How can the design incorporate modularity, flexibility, and ease of installation/disassembly to accommodate these potential changes while minimizing waste and environmental impact?

One feature of this prompt is that we hoped it would be accessible for engineers of all expertise levels. A public seating solution at a park or public transit stop is something that most people encounter and thus is appropriate for participants of all experience levels. Therefore, most participants, regardless of level of expertise, have some level of experience with the solution that they are designing for that can be applied to their discussion in the design task.

Another key feature of prompts is that they encourage participants to consider what are often under-incorporated sociotechnical factors [2]. In Scenario 1 of the above prompt, to account for a diverse group of users with varying body types and abilities, participants need to incorporate public health and human contextual factors to inform decisions about the solution. Scenario 2 leverages sociocultural contextual factors by having participants consider how to cater to a culturally and socially diverse population of users. Scenario 3 discusses eventual disposal and end-of-life considerations, and how to design this public seating solution for environmentally friendly disposal. In past studies, discussion of these under-incorporated sociotechnical factors has been significantly more common from practitioners than it has been in students [2]. Having more data about how students consider these factors will help illustrate the difference in sociotechnical understanding between experience levels.

Finally, the prompt has aspects of its design familiar to participants from a wide range of disciplines. For instance, the design of this urban area public seating system is most closely related to the municipal and structural subfields of civil engineering. Knowing how this system interacts with the operation of the surrounding sidewalks, streets, railroads, or other modes of public transport by the seating solution relates to the transportation engineering field. Participants involved in architectural or industrial design could address the need to make the form of the solution appealing for the public to use. Given that the design tasks encompass multiple types of expertise, the prompts are accessible to participants over a wide range of disciplines.

Preliminary Findings

Preliminary analysis of the data indicates that these prompts appear effective in facilitating collaborative sociotechnical discussion. In the excerpt below, a third-year student explores the conflict between human comfort and wellbeing and institutional authority:

Lila: I know there's a lot of cities that implement, like, anti-homeless and anti-skateboarding type of seating... those cities, like, are a lot less likely to install something like a bench, because they don't want anyone sleeping on it, or like, they don't want anyone skateboarding on the railing... the city can pick out whatever they want. It's not really a problem for them, but... it does kind of become a problem for the people that we're designing for. If, like, maybe, like, they need a larger seat. But the city that they're living in… doesn't really allow for public seating to accommodate for that." [052025_9]

The passage highlights how students can consider different factors such as community safety and comfort within engineering design contexts. In other cases, students discussed the role of tradeoffs in engineering decision making, and how different factors will relate to and impact each other.

Nathan: "It also minimizes... the costs from producing materials, acquiring materials, the whole manufacturing environmental cost is reduced. And waste ease of installation. That's the… the like duality I find with stuff like this like the easier it is to install the less secure it is. Or just stable and durable... Because, yeah, you could just like, you could just bolt everything together. But that's not the like the most secure. You want to make sure benches can't be like stolen." [050525_2]

Here, Nathan recognizes a push-and-pull between design factors going into the seating solution. Professionals were also able to engage with the scenario-based design tasks in meaningful ways as illustrated in the excerpt below.

Olivia: "What is the bench made out of? Is it a material that gets really hot in hot weather, really cold in cold in cold weather. Or something that stays more neutral. I guess there's some play there between, you know, a lot of the more durable materials of benches you see out there are like metal based, which you know, are going to heat up a lot more versus you know whether it's a plastic based bench or wood based bench, which maybe becomes a lot easier to tamper with. And not hold up as long." [21125_4]

Olivia brings up two factors that are important to the seating solution: durability and physical comfort. She understands that these two factors are trade-offs—that no design can be both perfectly durable and comfortable. Participants also considered the different ways that technical engineering choices would impact or constrain non-technical factors in the design context.

Olivia: "Maybe that is something that is decided more like community like whether it's city-based because like, each city kind of has their own benches. So like, maybe it's like on a city level, based on demographics of the city to kind of define that, and demographics of like, who are their primary users... If you have a park and like you know, maybe your primary user is going to be that family of four where it's probably going to be primarily parents... versus a bus stop, maybe you're looking at more, you know, working people, whether it's an urban environment where cars are hard or just folks that choose or don't want or can't have a car for a number of reasons. Which actually does definitely point... to needing more *accommodations for folks with disabilities, because, like... maybe it's not the easiest to get in your personal car and drive away as opposed to like, utilize a public transit system." [21125_4]*

Our preliminary analysis suggests that these sociotechnical prompts can generate rich discussions of technical and non-technical factors and how they relate to and affect each other. While students and professionals engage with the prompt in different ways, these differences will ultimately enable us to observe critical developmental processes as they concern sociotechnical thinking. That is, by examining the differences in ways that different populations of engineering students and professionals respond to the same sociotechnical prompts, we can plot a kind of developmental trajectory as it concerns sociotechnical thinking in engineering contexts.

Discussion and Implications

Our research thus far points to two areas of innovation within engineering education research and sociotechnical thinking. First, the scenario-based design tasks show promise methodologically, where they appear effective in yielding data to explore sociotechnical thinking across a wide range of engineering experience levels. Both students and professionals were able to engage with the design tasks in ways that generated rich discussions about diverse sociotechnical factors, and they did so in ways that seemed to reflect their relative expertise. Moreover, our findings extend existing sociotechnical research to account for collaborative engineering environments. Most other researchers have used individual interviews or used engineering artifacts (e.g., design reports) to explore sociotechnical thinking. These offer useful insight, and our method offers another way to explore sociotechnical thinking, with a specific focus on how it might take place collaboratively. Given that engineering work is highly collaborative [10], [11], [12], it seems important to explore sociotechnical thinking in collaborative contexts. Our current work addresses this need and offers insight into how engineers work together to consider technical and non-technical factors together.

Second, the scenarios have implications in engineering classrooms as an intervention that can encourage students to consider the relationships among technical and non-technical factors in engineering problems. Although the primary goal of the research was not necessarily to help students develop sociotechnical thinking skills, it is also possible that the data collection experience was one that offered opportunities to consider issues they might not have otherwise encountered in their curriculum. We therefore argue that implementing these kinds of scenario-based design tasks in engineering courses has the potential to help students think about a broader range of technical and non-technical factors during problem solving activities. Engineering educators have been making calls for engineers to consider diverse contextual factors [13], [14], and these scenarios offer spaces for students to begin that work. Educators should consider how scenarios like the ones developed here might be adapted within their own disciplinary contexts. Alternatively, educators could leverage tools such as AIG and human-in-the-loop approaches for their own contexts, starting with our scenarios as the model or template. Implementation of tools like these scenario-based design tasks could offer useful opportunities to connect disciplinary concepts to engineering contexts and real-world issues.

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Appendix

Focus Group Protocol

Modeling Sociotechnical Thinking Development – Retrospective Focus Group Protocol

Introduction

Hello and thank you for joining us. The purpose of this research is to gain a better understanding of how engineers engage with and think about sociotechnical topics. For example, sociotechnical categories may include considerations of environmental, sociocultural, economic, infrastructural, political, public health, technological, institutional, and geographical factors (Burleson). To do that, we will complete a collaborative, scenario-based design task and a brief follow-up discussion.

[Review Consent Form]

Your conversations during this activity will be recorded and will be transcribed and analyzed to conduct this study. Do you have any questions before we begin?

HIT RECORD ON ZOOM!

Design Scenarios

Now let's begin the design scenario, would you all be most interested in a design scenario about an Ergonomic Seating Solution, a Coastal Wind Turbine, or a Compact Solar Streetlight? Please take a minute or two to decide.

[Depending upon the group's choice, administer the according design scenario from the Design Prompts below]

Now that you have selected [chosen design scenario] please begin working, you will have 40 minutes to work through the scenario before a 20-minute follow-up focus group where we will ask some questions about your response to the design prompt.

Design Scenarios for Charting Sociotechnical Thinking

Option 1: Designing an Ergonomic Public Seating Solution for Urban Spaces

You are part of a team of engineers tasked with designing an ergonomic public seating solution for urban spaces, such as parks and transit stops. The seating system should account for design criteria such as comfort, durability, and strength while also considering the sociotechnical implications of its operation, including but not limited to social, political, cultural, or environmental impacts. Your task is to brainstorm and explore different solutions to this challenge that consider both technical and non-technical factors. To capture your solutions, you could do things like type ideas into the chat, use the whiteboard tools, or simply talk through your ideas—whatever you prefer. As a team, you will have 40 minutes to discuss these scenarios and questions and brainstorm as many different solutions that account for the sociotechnical implications of its development, operation, and use.

Scenario 1: A diverse group of users, including elderly individuals and people with disabilities, needs to use the public seating. How can the seating system be designed to accommodate different mobility levels, body types, and other human factors?

Scenario 2: The seating solution is to be installed in multiple cities with varying cultural norms and social dynamics. How can the design be adaptable to different contexts while still meeting the core requirements of comfort, durability, and accessibility?

Scenario 3: The seating solution may need to be relocated or reconfigured over time due to changes in urban planning or community needs. How can the design incorporate modularity, flexibility, and ease of installation/disassembly to accommodate these potential changes while minimizing waste and environmental impact?

Option 2: Designing a Wind Turbine for a Coastal Community

You are part of a team of engineers tasked with designing a wind turbine for a coastal community. The design criteria for the turbine should account for factors such as efficiency, energy production, durability, and maintenance while also considering the sociotechnical implications, which include but are not limited to as social, political, cultural, or environmental impacts. Your task is to brainstorm and explore different solutions to this challenge that consider both technical and non-technical factors. To capture your solutions, you could do things like type ideas into the chat, use the whiteboard tools, or simply talk through your ideas—whatever you prefer. As a team, you will have 40 minutes to discuss these scenarios and questions, and brainstorm as many different solutions that account for the sociotechnical implications of its development, operation, and use.

Scenario 1: The turbine is located near a wildlife habitat, and its operation is affecting the local bird population. How can the turbine be designed to minimize its impact on wildlife, while still generating sufficient energy?

Scenario 2: The turbine is located near a residential area, and the noise of its operation is disturbing the residents. The proposed turbine site is also near an area considered sacred or historically significant by the local indigenous community. How should the turbine be designed to minimize noise pollution and respect the needs of the community while still ensuring it produces enough energy?

Scenario 3: The turbine requires regular maintenance, which will be performed by a team of technicians. However, the community has limited access to skilled labor and sophisticated manufacturing capabilities. How can you design the turbine allow for easier installation and maintenance using locally available resources and skills?

Option 3: Designing a Compact Solar-Powered Street Lighting System

You are part of a team of engineers tasked with designing a compact solar-powered street lighting system to enhance visibility and safety on streets and sidewalks. The design criteria should account for factors such as efficiency, reliability, and light production while also considering the sociotechnical implications of the system, which include but are not limited to as social, political, cultural, or environmental impacts. Your task is to brainstorm and explore different solutions to this challenge that consider both technical and non-technical factors. To capture your solutions, you could do things like type ideas into the chat, use the whiteboard tools, or simply talk through your ideas—whatever you prefer. As a team, you will have 40 minutes to discuss these scenarios and questions, and brainstorm as many different solutions that account for the sociotechnical implications of its development, operation, and use.

Scenario 1: The street lighting system needs to adapt to varying weather conditions to ensure consistent illumination. How should the system be designed to optimize energy storage during sunny days and provide sufficient lighting during cloudy or rainy periods?

Scenario 2: The street lighting system is being installed in an area with high crime rates and homelessness, raising concerns about safety and security. How can the design incorporate features that enhance public safety while respecting individual privacy rights?

Scenario 3: The lighting system is being implemented in an area with limited access to traditional energy sources or skilled maintenance, such as remote or rural regions. How can the design of the system address the unique challenges of these areas, such as difficult terrain, limited infrastructure, and restricted access to maintenance resources?

Follow-up Discussion

Now I'd like to take a few minutes to explore/unpack/talk a little about how that went for you all. I have a few questions prepared, but we can talk about what was most important to you all.

Questions

- It seemed like [important factor that was discussed] was important throughout the design prompt. Would someone talk more about these factors' importance?
- How did you approach different trade-offs between relevant social and technical factors such as: [specific sociotechnical factors debated on throughout the design prompt]?
- What was the biggest challenge you faced during this design exercise? What made this so challenging?
- Is there anything you would do differently or advice you would give to another team of engineers working on this design task?

Closing

That concludes the design activity and focus group, thank you for your time and participation. If we have any further questions, we will reach out to you via the email you provided. If you have any additional questions about this study, please feel free to contact my advisor, Dr. Ben Lutz, at the email provided in the recruitment email.