BOARD # 225: Applying socially engaged design skills: Mechanical engineering students' senior capstone experiences (IUSE: EDU)

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Introduction and Background

Engineering solutions are increasingly expected to be not only technically sound and feasible but also consider human, contextual, and environmental factors in their designs. Developing students' abilities to balance technical factors with relevant social, cultural, and contextual factors is central to ABET accreditation (ABET, 2023) and provides a more holistic approach to engineering education. There is a growing need to train students to develop and apply socially engaged engineering and design skills (Nieusma & Riley, 2010), which considers contexts through a people-focused and environmental-focused lens (Center for Socially Engaged Engineering and Design, 2020). Traditional engineering education has typically prioritized technical competencies while underemphasizing social and contextual dimensions of engineering work (Niles et al., 2020). As a result, students may not be equipped with the skills to design successful solutions that account for tradeoffs to people and environments.

To support more comprehensive engineering design approaches, the Center for Socially Engaged Engineering and Design (C-SED) developed the Social Engagement Toolkit (SET), which is a collection of resources and lessons on various design and engineering topics, including the socially engaged design process model, problem definition and needs statements, requirements and specifications, stakeholder mapping, concept generation, development, and selection, prototyping, design interviews, and sociotechnical engineering problem-solving case studies. The SET was created to aid educators in integrating socially engaged engineering and design content in their courses, helping students develop these important skills. C-SED offers multiple modalities for integrating SET content into courses, including asynchronous online modules and in-person facilitated lessons tailored to a particular course focus. Prior research has demonstrated that the SET modules can support students in adopting recommended practices from each module (Lee et al., 2023, 2024; Loweth et al., 2020).

In this study, we investigated how the SET materials were applied by students as they engaged in a real-world engineering project in their capstone course. Data were collected from student reflections on how SET modules influenced their design processes and outcomes. The findings inform how the SET can support engineering instructors in incorporating socially engaged design principles along with traditional engineering content in their courses.

Study Design

Participants and Context

Four SET modules were implemented in a two-semester capstone mechanical engineering capstone design course at a large Western university designated as a minority-serving institution. Students were divided into 7 teams to work on engineering projects (3 industry-sponsored, 3 community-sponsored, and 1 student-led) and each team was composed of 4-5 students. All students were required to complete the SET modules and reflection prompts. Of the 32 students enrolled in the course, 27 students consented to participate in the study, allowing analysis of their responses. Student demographic information was not collected for this study.

SET Modules

The capstone course involved lectures and meetings with the instructor once a week. Students often needed to schedule meetings with their project sponsors and other stakeholders outside of

the course. Four SET modules that focused on design requirements and specifications (week 3), design interviewing (week 4), concept generation and development (week 6), and concept selection and prototyping (week 7) were used during the fall semester. The modules were provided as asynchronous learning on Canvas except for the Design Interviewing module. After going through the asynchronous modules, in-person workshops on each topic were presented during the lecture portion of the class. The learning objectives for each SET module are shown in Table 1.

Table 1. The learning objectives for the SET modules used in this study.

SET Module	**Learning Objectives**
Design Requirements and Specifications	- Describe the difference between needs and requirements - Describe the process of identifying requirements - Differentiate between requirements and engineering specifications - Translate requirements into their corresponding specifications
Design Interviewing	- Define the goals of a design interview - Recognize what goes into planning & conducting an interview - Describe different interview approaches and question types
Concept Generation and Development	- Understand and apply guidelines needed to successfully generate concepts - Use a variety of ideation strategies and tools to generate and develop concepts - Generate many concepts without evaluation
Concept Selection and Prototyping	- Organize and filter through potential solutions in a meaningful way - Use data gathered through the design process to effectively evaluate solution concepts - Objectively compare solution concepts against a need specification to determine what concepts to pursue - Demonstrate the value of prototyping at any stage of the design process - Understand when and how to use different types of prototyping techniques - Evaluate prototypes

Data Collection and Analysis

To study how the SET modules impacted students' processes and their project solutions, students responded to these reflection questions at the end of both the fall and spring semesters:

- Consider the information your team needed for your team's project this year. How did you gather the information you needed over the course of your project?
- Earlier this semester, we had training on Design Requirements and Specifications, Interviewing, Concept Generation and Development, and Concept Selection and Prototyping.
- How, if at all, did the training on [each training module] influence your team's process and/or solution this year? Please be specific in your answer.
- What were some challenges or things that did not go as expected in your team's project work this year? What do you think led to these challenges? How did your team respond to these challenges?
- What were some things that your team did well with your project? Please explain.
- What do you think your team could have done better in your project? Please explain.

Two researchers led the data analysis of the qualitative reflection responses by reading through each response and noting themes, following thematic data analysis techniques described in Patton (2015). The themes were iterated and grouped based on similarities. Two researchers discussed discrepancies and completed the findings.

Results

The findings represent patterns in students' processes and challenges incorporating the SET modules. The influences of the SET modules are summarized in Table 2 and further described in the following sections:

Table 2. Summary of how the SET modules influenced students' processes and their projects.

SET Module	**Influence on students' processes and their project outcomes**
Design Requirements and Specifications	- Provided guidelines for information gathering to understand stakeholder needs
Design Interviewing	- Prepared students to build rapport when meeting with stakeholders - Supported students in preparing appropriate questions for effective information gathering
Concept Generation and Development	- Helped students generate diverse concepts and share them with stakeholders. - Supported students in synthesizing concepts to develop final designs
Concept Selection and Prototyping	- Helped compare strengths and weaknesses of specific features that led to combining or selecting concepts - Guided students to iterate on their prototype after gathering feedback from stakeholders

Influence of the Design Requirements and Specifications Module

The Design Requirements and Specifications module emphasized the process of identifying requirements and translating them into specifications. Students were encouraged to spend time considering various requirements and specifications for their projects prior to generating potential solutions for their projects. Student reflections pointed out that the training provided guidelines for information gathering from their stakeholders to better understand their needs and expectations along with the limitations of their projects as shown in the following quote:

> "*I realize now that, without this training, it is very likely that* ***I would not have gathered the necessary information to truly understand the limitations and expectations of this project. As a result, without this training, I may have spent valuable time working on solution ideas that did not adequately address the project proposal.*** *By encouraging [stakeholder] to elaborate on the specific details of what our solution should entail, our team was able to generate creative, but practical, solution ideas."*

Influence of the Design Interviewing Module

The Design Interviewing module focused on recommended practices in planning and conducting interviews, including developing appropriate questions for engaging with stakeholders. Students indicated that they felt anxious meeting stakeholders for the first time, but their interview structure prepared them to build rapport when meeting with stakeholders. For example:

> *"The interview outline and training were helpful for me as they helped guide the first meeting with our mentor, and I felt more prepared because of it.* ***What made me most anxious was that we were to interview an actual engineer, not just any engineer, but one from [the company]. Additionally, I have never officially hosted such an interview before, so I had no idea where to start. The biggest help was the structure given, as it allowed us to build a relationship with our mentor and ask him open-ended questions.*** *It definitely helped us keep him talking for as long as possible."*

Training also provided support in preparing students with appropriate questions to ask their stakeholders for effective information gathering. Additionally, students emphasized the importance of learning to ask follow-up questions and gathering lots of information from their stakeholders:

> *"I found it helpful as a guide on how to structure the conversation with our stakeholders from the [organization]. When we used these skills with [our stakeholder], we found out I would look back at the lecture to* ***figure out ways to correctly word a questions and how to structure the interviews. The lecture about interviewing made me realize the important of asking follow up questions.****"*

Influence of the Concept Generation and Development Module

Students emphasized the importance of generating diverse concepts without evaluating them early in the process, which helped them share various concepts with stakeholders. In some cases, students generated unconventional, non-obvious concepts that ultimately became their final solution direction after a discussion with their stakeholders:

> *"We didn't know how crazy or how safe we wanted to be. There were some obvious solutions to our problem, but nothing was super outside the box before our concept generation process.* ***After some crazy ideas, we ended [up] landing on a crazy idea that we pitched to [our stakeholders] and his team seemed to really dig it.*** *We were generally surprised and the Concept Generation was the most effective part of this semester."*

Students also emphasized the value of considering numerous, diverse concepts that helped them ultimately synthesize aspects of their concepts to develop them into more complete concepts:

> *"By brainstorming numerous concepts and ideas, we were able to consider a variety of possible solutions and ultimately* ***ended up synthesizing aspects of multiple concepts****."*

Influence of the Concept Selection and Prototyping Module

Training on the concept selection portion emphasized the importance of comparing and evaluating concepts in a meaningful way. During this comparison step, students identified strengths and weaknesses of different features of concepts, allowing them to identify specific features that can be combined or selected to develop and narrow down their concepts:

> *"****Influence[d] our process by picking and choosing which parts of the prototypes that were ranked high and combine them****. Having to create a matrix and weighing the criteria, helped us narrow down our concept."*

Training on prototyping emphasized students to develop prototypes early and often, and leverage prototypes as a valuable tool during any stage of design. Students used their prototypes to iterate on their prototypes after gathering feedback, helping them understand aspects that need to be modified to better meet their stakeholders' requirements, as shown in the following quote:

> *"Initially, I wouldn't say I liked that we needed to prototype continuously. With one great idea, we were good.* ***As we progressed and our leader continuously came up with new ideas, I realized that prototyping was essential. For example, if some parts of the design were undesirable to the client, we would need to design again****."*

Discussion and Conclusion

The students articulated benefits of incorporating the SET concepts to support their design processes and project outcomes. Students described that the Design Requirements and Specifications module helped them have guidelines for their design projects and better understand stakeholders' needs. The Design Interviewing module guided on developing structured conversations with stakeholders for building rapport and effective information gathering. The Concept Generation and Development module aided them in considering diverse concepts that can be shared with stakeholders and synthesizing multiple concepts into their final designs. The Concept Selection and Prototyping module prompted students to compare the strengths and weaknesses of features that led to combining concepts and supported design iterations with their stakeholders. Using various SET modules to provide scaffolding to complement senior design course learning objectives provided valuable support for students working on their projects as they adopted recommended design practices and demonstrated important sociotechnical skills. Instructors can leverage the SET materials to emphasize particular skills or use multiple modules to support their course learning objectives when students are working on real-world projects. In conclusion, this study demonstrated how the SET modules facilitated students' understanding of these topics and how students applied them to support their design projects.

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