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Graduate Students' Experiences Designing Sociotechnical Modules for Introduction to Circuits Courses

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Abstract

Engineers are often faced with complex problems requiring both technical and social expertise, yet engineering education frequently neglects the social implications of engineering. To address this, our project integrates sociotechnical content into an Introduction to Circuits course. We created the Sociotechnical Electrical Engineering Stars (SEES) program to support seven graduate students in creating 50-minute sociotechnical modules, including PowerPoint slides, in-class activities, pre-class assignments, post-class assessments, and detailed instructor guides. Following a 1.5 day in-person summit on effective course design, students collaborated in pairs over the summer of 2024 to develop their modules, mentored by two electrical engineering faculty members and one sociology faculty member.

To evaluate the SEES program, the graduate students completed an end-of-program survey and participated in interviews about the level of support they experienced and the challenges they faced developing their modules. Overall, we found that the graduate students felt supported while still facing challenges with the program such as time constraints and conflicting expectations. They also struggled with designing their module, especially with integrating technical and social elements effectively and creating content tailored to both students and instructors.

Introduction

The majority of engineering undergraduate programs lack sufficient guidance on social and ethical responsibility in the field of engineering. Both the U.S. National Academy of Engineering and ABET accreditation emphasize the necessity to embed ethics and social responsibility to address ethical, global, cultural, social, environmental, and economic impacts [1]-[3] Research has consistently demonstrated the value of sociotechnical awareness in engineers. For instance, engineers must prioritize public well-being and ethical responsibilities in their work [4]-[8], understand the societal impacts of engineering solutions [9]-[12], and challenge cultural norms that dominate the field of engineering [8], [10], [13]-[15].

Despite these imperatives, most engineering undergraduate programs continue to emphasize technical proficiency, such as calculations and mathematical modeling, often at the expense of social considerations. Studies examining the attitudes toward incorporating sociotechnical topics into engineering education focus on the lack of social issues in traditional engineering courses [11], [12].

This paper is part of a broader NSF-funded project aimed at exploring effective strategies for incorporating sociotechnical topics early in the undergraduate curriculum**,** specifically the first course in Electrical Engineering, *Introduction to Circuits*. Our paper focuses on our latest efforts to design and pilot individual, sociotechnical modules. Specifically, in the summer of 2024, we facilitated the Sociotechnical Electrical Engineering Stars (SEES) program for engineering graduate students to learn about effective course design principles and create sociotechnical course modules. This paper will provide an overview of the SEES program and an evaluation of it, summarizing the extent to which the graduate students felt supported through the program and describing the challenges they faced when designing their modules.

Overview of the SEES Program

The SEES program was designed and facilitated by three faculty mentors: two are electrical engineering faculty members who have taught circuits and used sociotechnical modules in their courses, while the other is a sociology faculty member with expertise in sociotechnical dualism and depoliticization. Seven graduate students participated in the SEES program, which included a welcome meeting, an in-person summit, collaborative summer work, and a virtual showcase to present the modules.

The SEES Cohort

Seven graduate students from across the country participated in the SEES program. An invitation to participate was advertised through several venues, including the bimonthly listserve for the Educational Research and Methods (ERM) Division of ASEE and individual emails to electrical engineering colleagues to help recruit graduate students. We received 64 applications from students at all stages of their graduate careers in both electrical and computer engineering (ECE) and engineering education research (EER) programs. To ensure a variety of perspectives in the modules, from the application pool, we worked to select a cohort of students with diverse backgrounds and experiences, including variations in research focus (EER vs. ECE), gender, and nationality. The cohort included four EER students, Maria, Diego, Amelia, and Miranda (pseudonyms), and three ECE students, Jane, Rafael, and Joe. Among the seven students, four were women, three were men, three were domestic students and four were international students.

The Welcome Meeting

The program began in April 2024 with a welcome meeting over Zoom. This session introduced the students to the program's expectations: create a fifty-minute module for a circuits class that is connected to at least one technical learning objective. The module requirements included PowerPoint slides, in-class activities, pre-class assignments, post-class assessments, and detailed instructor guides. The SEES cohort was also expected to attend an in-person SEES Summit in May, collaborate remotely with a partner over the summer to develop the module, attend monthly meetings with the project mentors, and present their final module over Zoom at an end-of-summer showcase. Participants were informed that an NSF award would fully fund their travel to the SEES summit and they would receive a $2,400 stipend at the conclusion of the program.

The SEES Summit

Before the summit, students were asked to watch a recording of an existing sociotechnical module about the circular economy and electric vehicle (EV) batteries and the voltage divider, review the instructor guide for that module, and complete a survey on their perceptions of sociotechnical topics [16]. The 1.5 day, in-person summit in May covered a range of topics to help prepare the cohort for module development. After a short icebreaker, the mentors facilitated a 50-minute conflict minerals module and overviewed the EV battery module (which students watched before the summit) [17], presenting feedback from students who had participated in the modules during a circuits course. Participants then reviewed learning objectives, backward course design and constructive alignment, and tips for creating sociotechnical modules. Instructors overviewed the main elements of the modules – including the technical circuits course topics and relevant course learning objectives, learning objectives related to the sociotechnical content, and in-class activities – and then they reviewed a typical *Introduction to Circuits* course schedule.

Next, instructors discussed the challenges of teaching sociotechnical issues in engineering by introducing the concepts of technical/social dualism and depoliticization [18]. Then, at the end of the first day, the cohort brainstormed ideas for sociotechnical topics related to the circuits course and pitched their ideas to each other, and received feedback. The next day, each student was assigned a partner from a different discipline (EER or ECE) and together they developed a collaborative summer work plan and refined their ideas for their module.

Collaborative Summer Work

Throughout the summer (June-August) students in the SEES cohort devoted approximately eight hours each week towards their module. They met weekly with their partner to continually refine their module and receive feedback. They met with the two ECE mentors together and the sociology mentor individually, once a month. Before each meeting with the mentors, the students completed a bi-weekly report, outlining what they accomplished since their last meeting and noting any questions they would like to address during the meeting. The cohort received feedback from the ECE mentors in the meetings with their partner. They met individually with the sociology mentor to address the social dimensions of the module.

The SEES Showcase

In August, the program culminated with a virtual SEES Showcase. The students presented their modules, including the pre-class activities, in class activities, and post-class assessment to the rest of the cohort and faculty mentors. Each presentation was followed by a discussion of the module where the students received one final round of feedback. In the month after the showcase (by the end of September), the students revised their modules and submitted their final product complete with the PowerPoint presentation, pre-class assignment, post-class assessment, and detailed instructor guide.

At the conclusion of the program, each participant completed an evaluation form providing feedback about the program and participated in a semi-structured interview to reflect on their experiences in the SEES cohort. Specifically, we aimed to evaluate two elements of the SEES Program:

- How well supported did the SEES cohort feel by the program's structure?
- What challenges did the SEES cohort encounter when developing their sociotechnical modules?

In November, after the completion of the interview and submission of their final module, the graduate students received a stipend for their participation.

Data Collection and Methods

To evaluate the program we collected two types of data. First, we created an end-of-program survey using a Google form. The survey assessed cohorts' satisfaction with both the program and the module development process, the level of support provided, the value of collaborative work in pairs, and whether participants felt adequately prepared with the knowledge of effective course design to create their modules.

Then, to supplement the survey data, we conducted semi-structured interviews with each of the seven SEES graduate students. The interview questions were targeted at both the program as a whole and the student's individual experience designing their module. The questions focused on participant's motivations for joining the SEES program, their expectations, if those expectations

were met, the most valuable parts of the program, and the parts of the program that could be improved. The questions explored participants' preparation, experiences, and challenges they faced when designing their module. The full interview protocol can be found in Appendix A. The interviews were conducted and recorded over Zoom, transcribed verbatim using Zoom's transcription feature and deidentified before analysis.

The data analysis began with calculating descriptive statistics (mean and standard deviation) for the survey data, followed by an in-depth evaluation of two interviews to develop initial coding ideas. From this preliminary work, we created a draft codebook and applied it to the two interviews used to create the codebook in qualitative data analysis software, MAXQDA24. We then inductively coded the remaining five interviews, expanding the codebook as new codes emerged. After completing the first round of coding, the codebook was revised and recoded each of the seven interviews. To identify patterns and themes, we conducted a systematic analysis of interview quotes by code. By integrating data from multiple sources, we ensured a robust understanding of the SEES cohort's experiences and the program's impact.

Results

The findings indicate both strengths and challenges of the program's structure and module development process. Overall, the SEES cohort reported feeling well-supported through structured feedback, peer partnerships, and regular check-ins, though some wished for additional feedback from the mentors. However, the program timing and pacing, conflicting feedback, and varied levels of preparedness to create a course module created challenges for the SEES cohort within the program. Participants also struggled integrating technical and social elements in their modules while navigating conflicting feedback and ensuring their modules were both clear for instructors and relevant to students.

Perceived Support Throughout the Program

The SEES cohort generally felt well-supported throughout the program. When asked on the end-of-program survey "How supported did you feel throughout the project?", students reported feeling "very" supported (i.e., mean (M) = 4.70; standard deviation (SD) = 0.46 on a 5 point Likert scale from 1 = "not supported at all" to 5 = "very supported").

In the interviews, the SEES cohort echoed this level of support with many expressing appreciation for the structure and the feedback they received from peers and mentors. Jane positively reflected on the feedback process saying, "I was offered timely feedback through my partner and through [the ECE mentors] through our bi-weekly report. So yeah, I think that was good." This comment underlines the value of regular, structured check-ins, such as the bi-weekly reports, which allowed the cohort to consistently receive feedback on their work.

Maria repeated the sentiment, stating, "I feel, really supported all across the process." This remark emphasizes the overall sense of support and guidance the students experienced, suggesting that the program succeeded in fostering an encouraging and supportive environment.

Despite feeling supported throughout the process of the module development, some students expressed that they would have liked to receive even more feedback from the mentors. Miranda suggested,

> I kind of think maybe if we'd met with [the ECE mentors] separately …we could have had more frequent meetings that would have been good…. [T]hen instead of it just being like once a month, it could have been a little bit more often.

Joe expressed a similar thought, "I think, getting maybe more feedback from [the mentors], probably especially [the sociology mentor]. … would have been helpful." This feedback displays the importance of additional interactions with mentors to provide targeted support and clarify questions or concerns.

In addition to structured feedback, the program's organization was praised: Jane notes "I wanna say it was pretty well structured like getting the weekly meetings with a partner, bi-weekly reports, and feedback from [the ECE mentors], and then meeting with them three times before the actual [Showcase] presentation." This comment shows the multiple layers of support provided, and the mention of the meetings leading up to the final showcase shows how the program helped the cohort feel prepared for key milestones.

Effectiveness of Provided Resources and Training

Students in the SEES cohort had varied perspectives regarding the materials presented at the SEES summit. However, the end-of-program survey reflected a positive perception of preparedness to effectively design a course. In response to the item "Do you feel you had enough knowledge about effective course design to create your module?" participants indicated they did have enough knowledge (M=4.40, SD = 0.76 on a 5 point Likert scale from 1 = definitely no to 5 = definitely yes).

During the interviews, the SEES cohort offered a more mixed response. Some of the students felt the materials were very helpful in creating their modules. For example, Rafael said,

> [The summit] was a great help, because all the materials we got when we were [at the summit] and also while designing the course[were] shared with us by [the ECE mentors] and also the other students. They … helped us a lot to design this model.

This comment displays the collaborative nature of the program crediting both the mentors and their peers for providing useful resources.

However, some other cohort members did not find the materials presented to them to be sufficient to create their modules, particularly in the short timeframe. Diego said,

> I don't know if the materials were enough. I would say no because I ended up, we ended up talking more about this in our one-to-one meetings with my partner. And yeah, I guess that it's something that is not easily explained in two days… Maybe we can focus like what people are learning in those days, because some of us might need more emphasis on something, and some others might need more emphasis on something else.

This reflects Diego's struggle to grasp all the different aspects of the content in a very short period, and tailoring the sessions to address the cohort's varied needs might improve the summit.

Challenges with Program Pacing and Expectations

Another theme about the SEES program structure centered around the program's timing and pacing. Some felt that the summit was rushed and left them with limited time to generate ideas

and receive feedback. Additionally, some expressed frustration about the program extending into their academic semesters, which conflicted with their existing workloads. Joe described their surprise at the post-showcase requirement to submit a revised module by the end of September stating,

> I wasn't expecting the … tail end here that we'd have an interview and that there would be another round of feedback after the showcase. I was expecting the showcase to be like maybe a couple of tweaks. But I got some more significant suggestions … which were all just wonderful, but it's taking a lot more time than I expected, especially now that the fall semester started. I didn't allocate time for that.

Joe's explanation reveals the challenges experienced due to the misalignment between their expectations of finishing their module in August and the reality of needing to complete additional work during the start of the semester.

Navigating Conflicting Feedback

An additional challenge that students faced in the program was that they sometimes received conflicting feedback from the mentors and their peers, which complicated their efforts to refine their modules. Amelia said

> The biggest hurdle for me was how to design the curriculum… in the middle of the summer [the mentors] were like, "no, you really need to tie it back to intro to circuits." And so I feel like I wasted a lot of time going from "I know what my module is about" to "Oh, I have to fit my module in this box", when like, it's a new thing, right? People don't teach [my topic] in circuits, courses. And so it's not like I'm taking a typical lecture and adding an application to it. I was doing something, I think, a little bit more rigorous. So I feel like I lost some time there.

Here, Amelia describes the difficulty of having conflicting expectations with the mentors. Amelia struggled implementing new requirements in the middle of the program, while also balancing the technical social components of their module within the time constraints.

Joe echoed this concern saying, "Yeah, I think... part of the difficulty is that… the feedback we receive kind of has sometimes conflicts of interest." These comments underline the importance of ensuring alignment among mentors when providing feedback to reduce confusion for participants.

Benefits of Collaboration

Notwithstanding these challenges, the SEES cohort found working with a partner to be beneficial. In the end-of-program survey when asked "How useful do you find it working in pairs?", students responded that they found it very useful ($M = 4.6$ $SD = 0.74$ on a 5 point Likert scale from 1 = "not useful at all" to 5 = "very useful"). In the interviews, they commented that being paired with someone from a different discipline allowed them to have different skill sets, leading to stronger module development. Jane said "Yeah … we had complementary skill sets of engineering education and electrical engineering." This quote shows how interdisciplinary collaboration enhanced the module development and enabled students to combine their respective expertise. Most students also found that having a partner provided accountability and allowed for regular feedback throughout the process.

Additionally, one of the most appreciated aspects of the SEES program was the sense of community it fostered. The SEES cohort valued the opportunity to connect with like-minded peers and mentors working towards educating more socially responsible engineers. Maria described the experience positively saying,

> The best part about the program has been being able to connect with so many people from engineering education. There's a few of us around the country well, not around the country around the world, and well, being able to know other students that want to do the same thing that I want [was good]. It's a plus being able to connect with [the ECE mentors], they're really establishing in this topic. It's really inspiring for me.

Here Maria expresses gratitude toward the program and the opportunity to engage with peers and esteemed leaders in the field, making the program especially meaningful for them.

Difficulties in Integrating Sociotechnical Concepts

One of the constraints of the sociotechnical modules was that each module was required to connect to at least one technical learning objective in the circuits course, and the most significant challenge reported by nearly all of the students was establishing a clear connection between the social and technical concepts. Students found it difficult to strike a balance between the social and technical elements while also ensuring their modules were comprehensive but not overwhelming. Rafael reflected on this challenge saying,

> The most challenging part was actually connecting the social issue with the technical issue, that was most challenging for me. Because I know about those two things differently. I was not very aware of [how] these things can be very integrated, but when I started designing the module I came to understand that we can relate them together.

This quote shows Rafael's initial difficulty connecting the social and technical issues which were originally viewed as two distinct constructs. However, throughout the design process, they began to recognize how these elements could be integrated. Joe elaborated on their ongoing struggle to reconcile these two components sharing,

> And I think that's still something I struggle with even to now, and I don't think there's a right answer either. So that's part of the problem. I think everyone has a lot of opinions about how much is too much or how much is too little of either side of it. So I think that's for me the biggest struggle.

Joe not only talks about the subjective nature of the balance between technical and social elements, but also describes the challenge of narrowing the scope of their module.

Another consideration for the SEES cohort was creating a module that was both marketable to instructors and relevant to students, as they wanted to ensure their modules were not only adopted by instructors but also engaging for the students. Maria said,

> Well, yes, I think …you have to try to put yourself again as a student and as an instructor and try to think like if that makes sense, if it goes. If I were a student,

> does this make sense for me in a class. So making the connection was the most challenging part.

Maria's explanation shows how challenging it was to connect technical and social topics that would make sense to the students in a circuits class.

In addition to balancing content, students also faced challenges in ensuring their modules were clear and usable for instructors. Diego reflected on this difficulty saying,

> I think the most challenging part is describing it in a manner that is clear enough for the instructors that are going to use them. Because when I'm saying "critical thinking." if I don't explain what I mean by critical, then people are gonna use it in whatever way they understand critical. And this applies for so many words, so many concepts, and so many ideas that are there that because I know them and because I just wrote them.

In this reflection, they worried that instructors may misunderstand parts of their module and note that the constraints of time and feedback made it difficult to refine their work fully, but they also expressed optimism that continued efforts will improve their ability to communicate their ideas clearly. Despite these concerns, Diego values the process and believes the modules are worth pursuing, even if imperfections remain.

Discussion

The results emphasize both strengths and challenges of the SEES program in supporting participants as they developed sociotechnical modules. While the cohort felt well-supported by the structure of the program, citing the regular feedback they received from peers and mentors, partnerships they created with students from a different discipline, and the community of like-minded peers that evolved as strengths, several challenges emerged. These challenges included time constraints, unclear expectations for social and technical components, and varying levels of preparedness entering the program. Some of these challenges emerged because the three mentors' expectations were not aligned. While the two ECE mentors, experienced in teaching Introduction to Circuits, pushed for technical content that was accessible to other engineering instructors, the sociology mentor emphasized the social aspects of the module.

The cohort struggled to make a strong connection between social issues and technical learning objectives. They wanted to ensure that the sociotechnical connection was strong so that students would be interested and engaged in the topic and that instructors would incorporate it in their courses. This task proved challenging, particularly when trying to balance the technical and social components of their module. The conflicting feedback from mentors added to this complexity, though it was also a difficult balance to strike in general. Despite these challenges, the cohort still successfully created seven sociotechnical modules that effectively integrated sociotechnical content.

These results suggest potential improvements for future iterations of the program. Based on the feedback we received, we would recommend increasing the frequency of mentor feedback, ensuring the mentors' expectations are aligned to reduce confusion, clarifying timing expectations, and providing more guidance on how to successfully integrate the sociotechnical components of the modules.

Conclusion

The SEES program successfully brought together a diverse cohort of seven students to design sociotechnical modules for circuits courses with mentorship from three faculty members. Through a structured program that included an in-person summit, collaborative summer work, ongoing mentorship, and a final showcase, the SEES cohort developed complete modules that balance technical learning objectives with broader social implications. Despite challenges such as time constraints, conflicting feedback, balancing technical and social elements, designing modules that appeal to instructors, and ensuring relevance for students, the SEES cohort demonstrated remarkable collaboration and fostered a strong, supportive community. Their efforts resulted in the development of comprehensive modules, which are set to be presented in circuit classes in 2025.

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Appendix A – Interview Protocol

Part 1: Background [2 minutes]

Hello. Thank you for attending and participating in this interview about your experience in the SEES program this summer. My name is [interviewer] and I'm a graduate student in EER.

Today I am interested in hearing your thoughts on the SEES program this summer. The goal of this interview is to help us refine and improve this program in the event we want to do this again. In order to have consistency across our interviews I will be following a script. And to be mindful of your time, this interview will be no more than 45 minutes.

As you may know, this interview is a part of a study funded by the National Science Foundation. [The mentors] are developing ways to introduce students to social issues in circuits, and they would like to learn more about your experience creating some of these modules. Thank you for being here and for sharing your experiences.

In order to recall this conversation, I will be recording today's interview. Do you have any questions about that? If not, I'm going to enable the recording now.

(activate recording)

So, I want to begin by letting you know that your responses today will be anonymized to the best of my ability so that [the mentors] will not be able to attribute any comments you make to you or any other person in the cohort. To clarify, I will strip out any identifiable information in the interviews and [the mentors] will have access to the anonymized transcript data only.

In addition, your participation will be confidential to everyone outside of our research team. We may use your comments for our research, but your specific comments will not be attributed to you by name. And - you may choose not to answer any question at any time.

Finally, as a reminder, after your participation in this interview and the submission of your final instructor guide, you'll receive your stipend for participating in SEES in a few weeks.

So let's get started…

I know you are here today because, as part of the SEES cohort, you created a sociotechnical module for an introduction to circuits course. So I'm going to spend the remainder of today focusing on your experiences as they relate to the program overall and your own module development. These questions will build upon the evaluation survey that you have already completed. Thanks.

Part 2: Reflections on the program [35 minutes]

First we will talk about the SEES program overall.

1. SEES Program overview [15 minutes]
    a. Why did you initially apply to this program?
        i. What did you hope to get from being involved? Was there something about the topic of the program that interested you specifically?
    b. Did your overall experience meet your initial expectations? How so?
    c. What was the best part of the program?
    d. What parts of the program could be improved? What specifically could we do next time to make it better?

e. Now, we will talk about the development of your module.

2. Module development [15 minutes]
    a. Do you feel you had enough knowledge about effective course design to create your module? Explain
        i. Did you have any exposure to backward course design before the SEES Summit in May? Did the materials from the Summit provide good information for you? What other resources would have been helpful for you to learn about effective course design?
        ii. How familiar were you / are you with the Intro to Circuits course content? Did we sufficiently address the typical schedule and list of topics for the course during the SEES Summit?
        iii. How well prepared were you to design a set of learning objectives that were both technically related and sociotechnically related? Is there anything we could have done to help you feel better prepared?
        iv. Did you encounter any difficulties designing the assignments (e.g., the pre-class readings, the homework problems, the test examples)? What made it easy or how could we have helped make it easier (if it wasn't easy).
    b. What can you tell us about sociotechnical dualism and depoliticization? Did the SEES program help you understand these concepts better?
    c. How did these topics help you develop your module?
    d. What was the most challenging part about developing the module?
        i. How did you overcome that challenge?
    e. How could we have better supported you as you developed your module?
    f. Did you find it helpful working with a partner on different modules? How did you use the partnership to help develop your module? Were there others who you also consulted? If so, who, and how did they help?
    g. Is there anything else about module development you'd like to share?
3. Final thoughts [5 mins]
    a. Thank you so much. It is almost the end of the interview, do you have any questions? Or do you have any thoughts about your module or the program that you would like to share but you haven't yet?

Great, thank you so much for your candid feedback. We really appreciate your time. We will process your stipend within the next few weeks. Thank you.