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Student Takeaways from two Sociotechnical Modules in an ”Applied Circuits” Course

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Abstract

Engineering requires both an understanding of technical content and of social contexts. However, engineering education often separates these two areas. To address this, we designed and implemented several sociotechnical modules that connect a social issue to a technical learning objective in a typical "Introduction to Circuits” course. This paper focuses on the implementation of two sociotechnical modules in a second-year “Applied Circuits” course at a large public university in the USA in Spring 2025. The study examines student insights from two one-hour sociotechnical modules: one focused on energy burden and the other on power prioritization. Semi-structured interviews with nine students were analyzed through inductive thematic analysis. Results show that students report developing greater empathy and awareness of the social dimensions of engineering, along with a better understanding of the real-world limitations, trade-offs, and consequences involved in engineering decision-making. Students reported moving beyond abstract technical reasoning to consider how engineering choices impact people, communities, and resource-constrained systems. These insights closely align with ABET student outcomes related to sociotechnical design and ethical responsibility. Overall, the findings suggest that one-class-period sociotechnical modules integrated into technical classes can effectively promote sociotechnical thinking in technical engineering courses and support accreditation-aligned educational goals.

Introduction

Engineering is inherently sociotechnical. It requires both technical expertise and understanding of social issues. However, engineering often separates the technical content from the social context, leaving engineers unprepared for the complex challenges they will face in their careers. The National Academy of Engineering emphasizes that engineering is fundamentally sociotechnical [1] and advocates for incorporating ethics and social issues into engineering education [2]. Additionally, ABET accreditation requires engineering programs to have the following student outcomes: (2) “an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.” and (4) “an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.” [3]. However, many engineering programs struggle to do this well [4], [5].

One explanation for this disconnect is the persistence of the technical-social dualism in engineering education, which holds that engineering work is neutral and that technical skills should be valued over social contexts [6], [7], [8]. In response [9], sociotechnical thinking has emerged as a framework that emphasizes engineers’ ability to recognize, integrate, and respond to the inseparable social and technical dimensions of engineering [10], [11]. From this perspective, engineering decisions are understood as both shaped by social context and as producing social consequences, thereby challenging the view that technical problem-solving should be isolated from social issues.

Additionally, incorporating social issues in the engineering curricula has been shown to improve learning and motivation [12], [13]. Minoritized students, in particular, value sociotechnical discussions, which foster a broader view of engineering and enhance their sense of belonging [14]. Furthermore, researchers emphasize that meaningful engineering practice cannot be separated from social context: engineers must account for public welfare and ethical responsibilities [15], [16], recognize how engineering decisions are shaped by societal contexts [17], [18], [19], and critically examine the dominant cultural norms in engineering [10], [20], [21].

Despite the benefits and needs for integrating sociotechnical content into engineering curricula these topics are not typically integrated in engineering classrooms [16], [18], [19], [22]. This is likely due to many reasons, including that it is a challenge for instructors [23] because of a lack of expertise, limited time for developing content, and perceived relevance of sociotechnical topics [24]. To address these challenges and to promote sociotechnical thinking in engineering courses, we've engaged in work to make it easier for instructors to incorporate social issues into technical engineering courses, particularly second-year circuits courses. We created one-hour sociotechnical modules connecting a social issue to at least one technical learning objective typically found in the course, complete with a PowerPoint presentation, a detailed instructor guide, and assignments that instructors can use in their courses. This paper seeks to explore the impact of two sociotechnical modules presented in an "Applied Circuits" course in the Spring of 2025. Our guiding research question is: "How does participating in sociotechnical modules in an 'Applied Circuits' course foster student awareness of the sociotechnical nature of engineering?"

The Modules

Seven graduate students in electrical engineering and engineering education created several modules through the Sociotechnical Electrical Engineering Stars (SEES) program [25]. The SEES program, guided by two electrical engineering faculty mentors and one sociology mentor, featured a virtual welcome, a two-day in-person summit, three months of summer collaboration, and a virtual final showcase. During the in-person summit, the graduate students were trained in backward course design and course alignment, and taught about the challenges of sociotechnical integration, including how engineering curricula are typically grounded in the ideology of technical-social dualism, before developing their modules. In this paper, we focus on two modules from this program: one introduces energy burden, and the other introduces power prioritization.

Energy Burden

The energy burden module introduces the concept of energy burden [26] defined as the percentage of household income spent on energy. It links to core topics of power and energy. Students learn to calculate energy consumption and costs while examining the socioeconomic impacts of a high energy burden, particularly in disadvantaged communities. In class, they review key ideas such as energy poverty, the difference between power and energy, and how to calculate energy use through appliance power ratings. They analyze electricity bills and employ the Low-Income Energy Affordability Data (LEAD) tool [27] to assess energy expenses by geographic area. They evaluate energy-saving options, like comparing the power use of light emitting diodes (LED) versus incandescent bulbs and computing the savings. Lastly, they consider policy measures that can reduce the energy burden and foster sustainable development.

Prioritizing Power

The prioritizing power module emphasizes engineering and ethical considerations for providing reliable power in situations like power outages in hospitals. The module covers topics such as switches, series and parallel circuits, and power calculations. Students learn to prioritize power distribution based on critical needs and address issues like load shedding, redundancy, and maintaining essential services during outages. In class, students calculate the power in simple series and parallel resistor circuits. The instructor then stresses the importance of reliable hospital power and the role of electrical engineers in ensuring it. Discussions include causes of outages, their effects on healthcare, and challenges in regions with unstable power supplies. Students collaborate in groups to justify power needs in specific hospital wards and make strategic decisions during a simulated outage, using their initial circuit as a basis for a hospital model. They defend which ward (represented by a resistor) should be load shed, concluding with a discussion on the ethical implications of these choices.

Methods

After piloting the modules with small groups of students who had previously taken an introductory circuits class and refining them to enhance their impact and clarity [28], the two modules were implemented in the Spring of 2025 in an "Applied Circuits" course, with 53 students enrolled at a large public university in the eastern United States. This course is required for electrical and computer engineering majors, covers topics typically covered in introductory circuits courses, and is the first required course for the majors. The instructor was not part of the research team, but worked closely with the principal investigators of the project to ensure she was prepared to facilitate the modules in her course. The energy burden module was implemented in the first day of class, and the prioritizing power module in week 3 of the 15–week course.

Data Collection

Students who attended both class sessions were invited to participate in a one-hour, semi-structured, individual interview. The primary goal of the interview was to explore students' reactions to the modules and the lasting lessons they gained from them. Specifically, after the semester ended (more than ten weeks after students participated in the modules), we asked students about their general impressions, likes and dislikes, suggestions for improvement, and how they would summarize the key takeaways for a friend for each module. We then asked about their attitudes toward introducing sociotechnical content into their engineering courses in general, and how the modules may have influenced their views. We incentivized student participation with a gift card. Nine students participated in an interview (see Table 1). We recorded the interviews, transcribed them verbatim, then cleaned and deidentified them before analysis. Quotes were edited to remove disfluencies such as "like" and "um" to improve clarity.

Data Analysis

To analyze the interviews, we used thematic analysis with inductive coding [29]. We sought to identify patterns and commonalities across students' responses. After familiarizing ourselves with the transcripts, we developed an initial set of codes grounded in the data and applied them in MAXQDA24, revising the codebook as new insights emerged. Analytical memos helped us focus on recurring ideas, similarities, and differences across participants, informing the development and refinement of themes through multiple rounds of coding. Rather than being guided by theory, our inductive approach allowed themes and patterns to emerge organically from the data. This paper focuses on a set of themes representing students' key takeaways from the modules, which show how they developed awareness of the sociotechnical nature of engineering.

Table 1. Interview Participants

Pseudonym	Gender	Race/Ethnicity	Major	Year in school
Amar	Man	Asian	Electrical engineering	1
Brendan	Man	White	Electrical engineering	2
Ishaan	Man	Asian	Computer science	2
Ivan	Man	White	Computer science	2
Liam	Man	Black or African American	Electrical engineering	1
Molly	Woman	Asian	Computer engineering	1
Niko	Man	White	Electrical engineering	2
Noah	Man	Asian	Computer engineering	1
Quinn	Non-binary	White/Hispanic	Computer science	2

Results

The interview analysis revealed two overarching takeaways from the modules that reflect how students came to recognize engineering as sociotechnical:

(1) Students demonstrated a high degree of empathy, as they reported becoming more aware of social dimensions of engineering and how their engineering decisions can directly impact people's lives.
(2) Students recognized the real-world consequences of engineering decisions, acknowledging that engineering has limitations, trade-offs, compromises, and that it is sometimes about making the least bad choice.

Although these themes often overlapped, students primarily discussed how engineering decisions affect people when talking about the energy burden module. In contrast, reflections on the limitations and consequences of our engineering decisions were more frequent when discussing the prioritizing power module. Because these interviews were conducted at the end of the semester, these takeaways reflect not only the two modules but also the students' cumulative experience throughout the semester.

Engineering requires empathy and a recognition of social issues

Throughout the interviews, students described the modules, particularly the energy burden module, as prompting deeper consideration of the social and economic factors influencing their engineering work. They discussed how their decisions can affect daily lives and noted disparities in resource availability among communities. The energy burden module prompted reflection on the socioeconomic dimensions of engineering. Students also linked this module and the concept of energy burden to everyday life, infrastructure, and their personal behaviors. For example, when asked to summarize his key takeaways from this module, Brendan said,

> *"Goodness. Probably everything we have around us ... is powered. And so as a result requires energy, and we have to make sure that not only are the objects we're using reduce the energy use when possible, but that the infrastructure reduces it, and that our behavior also reduces it. Because I do remember there were a few different ways to tackle it at different levels."*

Months after the module, he remembered that engineering problems can require multilevel approaches. Particularly, at the infrastructure level, engineers have the most power to make changes and reduce the energy we use.

Both modules prompted students to consider the resources communities would have available, and how this resource availability would differentially affect communities. For example, Noah reflected that the modules made him consider the constraints faced by households or communities with fewer financial resources saying,

> *"It made me think about money and natural resources- saving money [and] saving resources so you can use as little as possible, yet still be able to have a useful output. ... And I thought about how that could be applied in certain situations where some people or communities might not have that much money or natural resources to use."*

Beyond the availability to resources, students described a newfound appreciation for how engineering concepts relate to real people and real use cases. Amar explained how applying circuit topics to the real world was very eye-opening because it helped him realize how these abstract topics relate to more complex systems (like a hospital). He said,

> *"This whole time we had been learning about these abstract circuits, and the second you actually put them into a real-world setting, that's when you really realize these are real people's lives. These are real buildings or these are real use cases, and a lot of the times we just kind of get distracted in a way. We're only focusing on the theory, but not always like the application to the real world."*

Building on this idea, Ishaan also emphasized the importance of looking beyond technical details when reasoning through an engineering problem. He said,

> *"Key takeaways? I would say it's strictly not just an analytical decision that you have to make… it's more of a multifaceted decision. You have to consider multiple factors when you're making a decision."*

For several students, the social issues presented in these modules were ones that they had not previously encountered in either their engineering coursework or in general. For example, Amar noted, *"They brought up new issues that I never would have thought of existed."* And Molly explained that these modules prompted her to think about things she never thought of before, but by introducing these concepts it motivates her (and could motivate others) to study more knowing their work has an impact on people. She said, *"It was actually never something I really considered before… I hadn't taken a lot of engineering courses before and so I didn't have really any experience of them introducing social issues because a lot of them were just getting the basics down. But it just showed me that by introducing the social aspects, it might motivate people to become better engineers, or like study harder per se, because it shows you your work in the future will have a future impact on people. So I think it's very important."*

Taken together, these students' reflections show how the modules helped cultivate empathy, prompting them to consider the social implications of engineering work. Through these modules, the students incorporated social perspectives with their technical reasoning.

Engineering has real-world limitations and consequences

In the interviews, when discussing both the energy burden and prioritizing power modules, students consistently described a growing awareness that their engineering decisions can have real-world consequences (both positive and negative). While the energy burden module introduced ideas about resource limits and the impacts engineering has on people, the prioritizing power module prompted a more explicit reflection on trade-offs and the necessity of making decisions under constraints, a key feature of engineering practice. They described a shift from viewing circuits and electrical engineering as an abstract concept to understanding that the field is interconnected with social, economic, and ethical systems.

Students talked about the modules prompting a shift in their thinking, especially about how we typically take resources for granted. Engineering students typically view power and energy as limitless resources, but when discussing the energy burden module, Ishaan said,

"Key takeaways… So we learned power [and] energy... But then, if I wanted to summarize a greater, like a larger, higher level takeaway, I would say, maybe I feel it's really be mindful about what you're using. Or look into everything that you use, don't take everything for granted, because I feel like we do, that a lot, even [with] water or electricity, whatever it may be."

In this quote, Ishaan downplays the technical aspects of the module and instead relates a higher-level takeaway, that one should not take things for granted. Noah expanded on this idea, saying, *"There's a limit to what we can do as engineers, and that everything has a cost, and people may not be able to pay that cost."* When talking about the prioritizing power module, Ivan expanded on how students don't normally think about not having enough resources in these types of classes. He said,

"Yeah, it just introduced the idea that power isn't really… all ups. It's a mix of a rule of ups and downs… I mean. engineers always have to do that risk… and weigh the costs and benefits of things. And I think… throughout the entire semester, we don't really touch on [the] idea of not having enough power or not having enough energy to supply the circuit… But I feel like it's always good to introduce the idea that you might not have enough power or energy to and you always have to verify. Do you have enough power?"

Students also recognized how seemingly small technical decisions can have large-scale impacts. Ishaan described how he was reevaluating the long-term implications of choosing LED versus incandescent light bulbs. He said.

> *"I usually take [things] for granted, but, now, actually like examining it I'm starting to realize how much more sophisticated everything is, and how these small decisions that we make like… LED light bulb versus another type of light bulb, and…how that cost added up… I never really thought about if… even at [my university], or any big university, if I was using a million of these light bulbs versus a million of like the latter kind and over 10 years, how much money… that would save for the university.... So I feel that was [a] more practical thing that I took away, and it sort of put into perspective how important that is."*

He described recognizing the long-term financial and environmental implications of such institutional decisions. This realization expanded his understanding of how some seemingly small decisions can affect the energy consumption of large communities.

Another idea surfacing from the interviews was students' recognition that engineering choices have consequences, and that these consequences can be dangerous or can have serious ethical implications. When talking about both modules, Niko said,

> *"I think that the average college student quote unquote especially engineering students, can be uncomfortable when thinking about consequences of the actions of the companies that they're probably gonna go work for. And so any information that involves calculations that show a student how dangerous or otherwise unsafe something that can be designed can be, I think that's important for humbling people who want to change the world."*

Several students described beginning to grapple with the trade-offs and compromises that engineering may require in the prioritizing power module. In this module, they truly recognized constraints and that they needed to think of the system they are designing in a more human way. For example, Brendan said,

> *"In the real world, or in a realistic system, constraints are more than design parameters and their necessities and trade-offs. That must be considered and are more than just technical capability, but also the needs of the system in a more human way sometimes."*

In this module, they were required to use their knowledge of both the technical and social requirements to make a decision. Liam said,

> *"Okay. I would say, the engineering decisions we make have a real impact on people. And it's very important to really think about what you're doing and use your skills and also your own judgment, outside of the technical aspect of things, to make a decision."*

Students also discussed the pressure that's associated with high-stakes decision-making. Amar talks about what it's like to make a mistake when making these decisions under the pressure to be right. He later went on to say that he brought this up because he himself made a mistake when doing these calculations that impacted his decision. He said, *"And also just, you know, the I guess it wasn't just the fact that the situation was urgent, but also was something that kind of immersed the whole class…. Usually, you're like laid back in a lecture. But all of a sudden it's…these heated debates and discussion, and this newfound passion that you don't usually get out of, you know, regular circuits, discussions… [This] hospital lecture, I guess, did a really good job of like making people that usually we're just learning this concept of parallel and series circuits to suddenly, like passionately, you know, considering the ramifications of what if our calculation is wrong."*

Overall, across both modules, students reported understanding the consequences of engineering decisions and of how their actions as engineers will affect people. Through engaging with constraints and trade-offs, students recognized that engineering decisions are inseparable from social, economic, and ethical consequences.

Discussion

In reflecting about both the energy burden and prioritizing power in hospitals modules, students demonstrated sociotechnical thinking. They expressed an empathetic understanding of the communities affected by engineering systems and realized that engineering work often involves real-world limitations, consequences, and trade-offs. Although more students tended to associate the energy burden module with an enhanced understanding of social issues, and the prioritizing power modules with constraints and the consequences of engineering decisions, both modules contributed to a broader shift in students' perspectives of engineering as human-centered and embedded in the real world.

These takeaways are closely connected to the intentional design of the modules: making sociotechnical considerations relevant and inseparable from technical considerations. The modules were designed not only to support new sociotechnical learning objectives but also to align directly with the existing learning objectives of a typical circuits course. For each module, we (1) identified relevant technical learning objectives—such as "compute the relationship between power and energy consumed by a circuit element" and "analyze the current, voltage, and power in a circuit with multiple branches"—and (2) developed complementary sociotechnical learning objectives, such as "compute the relationship between household income, energy costs, and energy burden" and "describe the engineering and ethical decisions involved in prioritizing power allocation across healthcare uses." Then, using backward course design [32], we developed learning activities and assessments for the module to align with both the technical and sociotechnical learning objectives. Thus, sociotechnical considerations were integrated alongside core technical topics rather than treated as separate or supplementary.

Integrating the sociotechnical content with the technical material in this way helps students see the sociotechnical modules as relevant to engineering, thereby minimizing the resistance they might express to additional unrelated content in the course. This reduced resistance is consistent with our prior work, in which we found that students perceive such modules as "real-world" engineering when they see connections to the course's technical learning objectives [30],[30], [31]. Given that Circuits is one of these students' first engineering courses, helping them see the field as sociotechnical rather than solely technical prepares them for their future coursework and careers.

While the opinions of the nine students we interviewed may not represent all 53 students in the course, all the students interviewed found the modules valuable and identified the sociotechnical insights they have gained. We view this work as an accessible first step toward greater sociotechnical integration, rather than comprehensive integration. The modules were designed to be realistic for engineering instructors to implement in their existing courses.

Additionally, students' takeaways from these modules align closely with ABET student outcomes, especially outcomes 2 (an ability to design engineering solutions that address specific needs while considering public health, safety, welfare, and various global, cultural, social, environmental, and economic factors) and 4 (an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, considering the impact of engineering solutions in global, economic, environmental, and societal contexts) [3]. Students consistently discussed a newfound awareness of how engineering decisions can affect communities, how resource limitations can shape their design choices, and how ethical considerations should expand beyond technical ones. These modules also helped students develop the ability to evaluate trade-offs and constraints, which are essential to achieving ABET outcomes 2 and 4. The students' discussion of limited power supply and cost constraints showed that they were not only identifying social and economic considerations but also integrating them into their decision-making with technical requirements.

Conclusion

We implemented two sociotechnical modules, one on the energy burden and one on power prioritization, in an "Applied Circuits" course. Based on data from interviews conducted after the modules, our findings show that these modules effectively supported students in demonstrating the sociotechnical nature of engineering. Students not only recognized the ethical and social dimensions of their decisions but also articulated how technical choices have broader implications.

These findings have significant implications for engineering education, given that circuits is often one of the first discipline-specific courses students take in their second year. Although students may encounter social content in first-year engineering courses, embedding sociotechnical topics in foundational engineering course signals that these topics are integral to engineering and not peripheral. We showed that one-class-period, embedded modules can have lasting impact on students, effectively advance ABET outcomes, and foster sociotechnical thinking in a traditionally technical course.

While these modules don't achieve the ultimate goal of significant sociotechnical integration, they do represent a realistic first step in the right direction, offering tools to make it easier for instructors to incorporate sociotechnical topics in their circuits courses. Before sharing the modules more broadly, future work for this project will involve implementing and evaluating our five modules across a variety of engineering classrooms, including in circuits classes for other disciplines (e.g., biomedical engineering), different institutional contexts (research-intensive and teaching-focused), and different modes of instruction (e.g., in-person and online classes). Overall, these results demonstrate the value of incorporating sociotechnical topics into undergraduate curricula to advance both professional responsibility and accreditation-aligned educational goals.

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