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What Is Engineering and Who Are Engineers? Student Reflections from a Sustainability-Focused Energy Course

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Abstract: In the spring of 2021, the University of San Diego's Department of Integrated Engineering taught the course, "Integrated Approach to Energy", the second offering of a new required course, to nine second-year engineering students. The sociotechnical course covered modern energy concepts, with an emphasis on renewable energies and sustainability, and it exposed the students to other ways of being, knowing, and doing that deviated from the dominant masculine Western White colonial discourse. Following the course completion, we interviewed five students by using a semistructured protocol to explore how they perceived of and communicated about engineers and engineering. We sought to identify the takeaways from their course exposure to sustainability and the sociotechnical paradigm, which were central to the course. The findings suggest that the students were beginning to form sociotechnical descriptions, and that they were still developing their understanding and perceptions of engineers and engineering. Moreover, we observed that they were still wrestling with how best to integrate sustainability into those perceptions. There was an a-la-carte feel to the students' conceptualizations of sustainability as it related to engineering, as in, "you can 'do' sustainability with engineering, but do not have to". We argue that engineering students likely need these pedagogical paradigms (sociotechnical engineering and sustainability) woven through the entirety of their engineering courses if they are to fully accept and integrate them into their own constructs about engineers and engineering.

Keywords: sociotechnical engineering; sustainability; energy; higher education; interdisciplinary; qualitative methods

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1. Introduction

In the spring of 2020, The University of San Diego's Department of Integrated Engineering offered a reimagined energy course for second-year engineering students, which emphasized sustainability [1,2] and a sociotechnical approach that was informed by culturally sustaining pedagogies (CSPs). By sociotechnical (as opposed to "technocentric"), we refer to an engineering paradigm with social contextualization and the considerations that are irretrievably knitted into it, with an equal valuation to the technical [3–15]. Sustainability and sociotechnical concepts in engineering are foundationally connected, as approaching engineering education and practice through the sociotechnical paradigm is essential if we are to design a sustainable future. Furthermore, by valuing the social dimensions in the course, CSPs acknowledge the students' home and community cultural and linguistic practices as assets, and actively welcome them into the classroom [16–18]. In this course, we drew from CSPs to create a space where the ways of being, knowing, and doing of communities of color were acknowledged and were made part of the curriculum, rather than eradicating them or making them invisible [17,18]. We further describe the course design and the institutional context for the course below.

Following the first course offering, we shared the course design (the learning objectives, content, and pedagogical approach) and the preliminary findings about the students' learning and the course impact in several publications [19–23]. In the spring of 2021, we offered the "Integrated Approach to Energy" course for a second time. At the end of the semester, we interviewed five students from the class using a semistructured protocol in order to explore how they perceived and communicated about engineers and engineering. Our goal in this case study was to explore the students' perceptions of engineers and their practices after taking the course, which deviated from the traditional discourse of engineering as a purely technical endeavor and emphasized sustainability. We sought to identify the takeaways from their course exposure to sustainability and the sociotechnical paradigm. The findings suggest that the students were beginning to form sociotechnical descriptions while still developing their understanding and perceptions of engineers and engineering. Although the students were beginning to recognize engineering as a sociotechnical field, they were still wrestling with how best to integrate sustainability into those perceptions.

1.1. Institutional Context

The University of San Diego (USD) is a private contemporary Catholic liberal arts institution with a mission, a vision, and values that focus on peace, justice, sustainability, and on confronting humanity's urgent challenges [24]. USD's Shiley-Marcos School of Engineering houses five undergraduate-focused departments: computer science, electrical engineering, industrial and systems engineering, mechanical engineering, and integrated engineering. This paper focuses on the student experiences in the integrated engineering (IntE) program. In addition to their liberal arts education requirements, IntE students complete a set of engineering courses in the major that were designed to develop a broad technical foundation, as well as a concentration in an area of their choosing [25]. The students can opt to design their own concentration, or they can complete a predefined concentration in biomedical engineering, embedded software, sustainability, or law. This paper mainly focuses on the IntE students who were pursuing a sustainability concentration; however, all of the IntE engineering curriculum is sociotechnical and is situated within a wholistic paradigm in order to cultivate student capabilities in designing a sustainable future.

1.2. Course Design

We have shared detailed descriptions of what we teach and how we teach this course, including the learning objectives, the content, and our pedagogical approach, in previous publications [20]. Briefly, and relevant to this study, the course covers modern energy concepts, and it emphasizes renewable energies and sustainability. During the first offering of the course, we discovered that the students had a wide range of misconceptions about sustainability [22]. In the version of the course that is described in this paper, we added a new module early on in the course that explicitly defines and examines sustainability. The students are guided to use the PESTLE framework (political, economic, social, technical, legal, and environmental) to analyze energy challenges from a multidimensional and interdisciplinary perspective [26]. The course emphasizes the importance of "place" (i.e., learning that is relevant to the local context) [27–31]. Students are exposed to other ways of being, knowing, and doing that deviate from the dominant masculine Western White colonial discourse [32–37]. For example, in traditional engineering education contexts, the textbooks and classroom sample problems are often based on stereotypically masculine interests (i.e., cars, sports, and guns), and they skew towards incorporating White male characters [38]. Conversely, this class emphasizes learning experiences that feature examples from a diverse range of perspectives and cultural contexts. Moreover, as they are informed by CSPs, which emphasize connecting the students' course experience to their lived experience, the delivery and content were designed to be relevant to students [16–18].

2. Materials and Methods

At the end of the Spring 2021 semester, we invited all of the students from the class (nine in total) to participate in 30–60 minute semistructured interviews. Five students chose to participate in the individual interviews with the first author. Because the interviews occurred during the COVID-19 pandemic, they were all conducted via Zoom. The authors of this paper collaborated on the design of the semistructured interview protocol, and they based it on their experiences of and their research on the incorporation of the social context into engineering. The first author conducted the interviews separately from the other authors, as the other authors are all professors that the students would have, or would have had, in their major courses. The interviews were designed to be brief, to develop rapport, and to elicit participant perspectives on engineering, the energy course, and the aspects of engineering design that they prioritize (e.g., social, technical, etc.). The protocol was piloted and used with students in previous work [22]. For this study, we focus on a subset of the protocol. Specifically, we asked the students:

- Why did you choose to major in engineering?
- How do you define engineering?
- Please describe an engineer.
- What kinds of problems do you think engineers might solve?
- What differentiates engineers from non-engineers?

In order to maintain student anonymity, the first author employed pseudonyms to identify the students in this paper (Table 1). The students (four women and one man) were mostly sophomores (one junior) and were each majoring in integrated engineering, with one student double-majoring in environmental science. Four of the students were pursuing a concentration in sustainability, and one was pursuing an individualized plan around business. The remaining authors remain unaware of which responses corresponded to each student in order to protect the students' privacy.

Table 1. Study participants.

Pseudonym	Year
Aliana	Sophomore
Bryce	Sophomore
Lucy	Sophomore
Meg	Junior
Sonia	Sophomore

We used a hybrid deductive and inductive thematic analysis approach to analyze the interviews [39]. Throughout this process, the first author led the coding and the interpretation of the data, but the entire project team discussed the findings. Any disagreements were resolved through discussions with all the authors. We used our driving themes of interest from the interview questions as a starting point, and we then went through an iterative process of reading through the interviews and observing how they mapped to the themes. We assigned preliminary codes to the data to describe the content, and we searched for, reviewed, and finalized four themes across the interviews: (1) "Why engineering?" (i.e., personal motivations for pursuing an engineering degree); (2) "What is engineering?"; (3) "Who are engineers?"; and (4) "What do engineers do?".

Across all of the interviews and themes, we also looked for whether and how the students incorporated sustainability into their responses in order to see how they connected sustainability to themselves, to engineers, and to the field of engineering, after taking the course. We similarly looked for evidence of their experiences with the sociotechnical engineering paradigm.

3. Results

3.1. Why Engineering?

Consistent with the many studies that have examined students' motivations for studying engineering, the students skewed towards mentioning an affinity for the technical and quantitative aspects of engineering, including math and science, and the analytical skillsets, as they shared their motivations for pursuing an engineering degree. For example, Bryce referenced his childhood love of Legos, a robotics club, and playing with breadboards as indicative of his predisposition to enjoy engineering. In Sonia's words, "I didn't really know what I wanted to do, but I've always been good at math and science. I knew that I did not specifically want to do science. [Engineering] seemed like something that I could combine my skills into." Similarly, Aliana said, "I'm very into math and science ... I really wanted to become more analytical and a critical thinker because I like to challenge myself." Lucy discussed her motivation to study engineering in a way that departed from the math/science/analytics rhetoric to include something more:

> *When I first came in, I was actually debating between math and engineering because I think of myself as a more analytical person and I like doing this (sic) hands-on, very calculated types of problems. Then I ended up choosing engineering because I liked that it was more well-rounded I guess, that I would be able to do things outside of math, but still be able to do those types of problems in statics or physics and stuff like that. I also liked that engineering is more than just numbers. It's a lot about ideas too, and I really like that part of it.* (Lucy)

Meg took things a step further and described her vision for applying engineering in order to "make a change":

> *When I looked at engineering, I thought those were the kinds of jobs where they make the change, they create the change, and they come up with the solutions rather than [scientists who are] just doing the research and finding what the issues are and things like that.* (Meg)

All but one of the students who were pursuing the sustainability concentration talked about their motivation for their concentration (Meg never mentioned sustainability or her concentration). Bryce's motivation had to do with scale, and his perception that pursuing sustainability would enable him to take on larger-scale projects. In his words:

> *I don't know. I like electrical engineering, but I don't really like the little things. I like bigger-scale projects, and I feel like with sustainability, you can do bigger-scale stuff.* (Bryce)

Sonia had a desire to engage in something "beneficial", and she saw the sustainability concentration as helpful to that goal:

> *I want to be able to have a job that is beneficial in some way. For me for the sustainability focus, hoping to be able to do something that will benefit in some way, even if it is small ways, it could do with engineering like new sustainable methods as we move on with the climate crisis, or in infrastructure, but something that I can do that, hopefully, will make an impact.* (Sonia)

Lucy similarly hoped to "make a difference", and she also selected the concentration out of passion:

> *Sustainability, I've always been passionate about learning about that kind of thing, about that kind of stuff. When I try looking at it from a personal perspective, I think that I'd want to make differences. I'd want to start solving those problems. I'd want to learn about how to help mitigate some of these issues.* (Lucy)

In sum, while the students described the typical motivations for pursuing engineering (i.e., an aptitude for math and science), they also articulated some newly formed ideas that were aligned with the motivations that we hope to ignite within our students along the way, such as the opportunities to contribute to the solutions to humanity's urgent challenges and to design a sustainable future.

3.2. What Is Engineering?

The students identified engineering as a result-and-solution-oriented practice, with an emphasis on problem solving. For example, Bryce defined engineering as, "where theory meets the practice. For example, it's where physics and math, where you actually see the results and it's not just theory. It becomes real. It's that trial and error where you can get the theory to the real results". For Meg, it includes "looking at issues from different perspectives and creating solutions to problems, or creating systems or technology to help in finding solutions to issues". In her definition, Sonia states that the reason for engineering efforts is, "trying to make new innovations and build new things that will benefit society and make things easier". Aliana also mentioned innovation in reference to engineering:

> *Engineering, it's not just building, it's like an innovative, hands-on approach to creating, building things ... a very analytical, hands-on approach to how we get literally all the products that we have now. Yes, like creating things that we just use in the world.* (Aliana)

While Sonia distantly included people in her concept of engineering through a reference to "society", Lucy was the only one to mention "people" directly; she was also the only student to mention the environment:

> *I think that engineering is really just problem solving, but not just mathematical problem-solving. It has to do with problem-solving in a more broader (sic) aspect where you have to think about the people, the environment, and then like the actual calculations, the math that goes into it. It's like problem solving, but it's a really big problem that involves a lot of different things that you have to keep in mind.* (Lucy)

Notably, as the students talked about engineering, they largely did so in a distant and general manner, without personal references or examples (see studies about critical discourse analysis, particularly nominalization and transitivity, e.g., [40]). The emphasis was largely on the "doing", the "fixing", the "solving", and the "building", which is indicative of a nascent understanding of what engineering is [41]. An exception is a comment that Lucy made, in which she sets her personal engineering apart from others with a passion for building things:

> *I think some people in engineering, they strictly love to build things or put things together, like wires or a building, but also engineering could have a more broad (sic) approach, like the way I'm doing it, where you learn a certain way of thinking, and then you can go out in the world and just apply that.* (Lucy)

Bryce also saw the field as open and that, "there's not a really set barrier to what [engineering] could be. It can be like art, it can be everything".

This comment is a budding conceptualization of engineering as an open and welcoming field that is more than just the technical. In some instances, the student comments indicated that they were pushing away from an old idea and what engineering is not ("it's not just building"), which we hope is indicative of a gathering of momentum that can be used to propel students forward towards the discovery of a new idea as to what engineering is.

3.3. Who Are Engineers?

The action-/result-/solution-oriented thread carried over from the student descriptions of engineering into their descriptions of engineers. For example, the emphasis on "doing" is again exemplified in one of Bryce's reflections on the difference between engineers and scientists:

> *I think the difference between [an] engineer and, for example, a scientist is, the scientist has the scientific method and they have all these hypotheses. Engineers are more along the lines of just do, then fix, and then try again ... I think the try and do and then restart, and try and do again is the main difference and thought process between this and most other professions.* (Bryce)

Meg also focused on solutions and creating when she described engineers with the following statement:

> *I would say definitely a solution-based mindset. I see engineers definitely also working in technology and helping with advancing technology, creating new technology, and making changes that they want to see that they're passionate about.* (Meg)

Markedly, multiple students mentioned "passion" in their responses. Meg was not the only student to describe an engineering mindset; the others also described following a process in order to "narrow" and solve problems. For example, in Aliana's words:

> *I think engineers are super able to take a lot of things into consideration and really break things down step-by-step. They're able to juggle a lot of ideas in their head and bring it down to a narrow point where they can solve problems or build things. That's what I envision as an engineer.* (Meg)

Analogous to how Bryce described engineering as a discipline without "set barriers", several students were limitless in their conceptions of engineers. Aliana expressed her view that there is "no mold" for engineers, and she referenced her personal experience for that opinion:

> *I see engineers as very fluid. I don't think there's a set mold to them necessarily. I feel like other people perceive them just like quiet people who are narrow-minded right into their work, but I don't know ... My experience has been super different. I think there isn't really a set mold for an engineer.* (Aliana)

Lucy echoed this sentiment as she searched for words to describe engineers:

> *When I think of how they are, I don't know if there's a specific thing, or a specific word that I would describe an engineer, because it all varies. I don't know if that makes sense. I can't think of just one word that could describe an engineer.* (Lucy)

A connecting thread to the student responses was that they did not see engineers fitting into a tidy box. Rather, they saw engineers as multifaceted and multidimensional.

3.4. What Engineers Do

3.4.1. People-Oriented

Though there was a dearth of responses that mentioned "people" with respect to engineering in general, great emphasis was placed on "people" when the students reflected on how engineers spend their time. For example, Lucy made mention of "people" with respect to engineers that talk to people to solve problems:

> *I think that they probably talk with so many different types of people, not only engineers, but maybe clients, maybe supervisors. They talk to so many different types of people because they have so many different types of problems to solve.* (Lucy)

In this comment, the mention of "people" seems to focus more on working with people, rather than benefitting them. Meg states that engineers are, "definitely surrounded by a group of people, lots of teamwork and collaboration ... I see hanging out with other people and definitely very active, I would say, not the type to just sit around and not do anything". Sonia was not sure what engineers did, but she hoped that it was people-oriented:

> *Honestly, I really don't know a lot of specifics about [what engineers do in their] jobs, which is not great for that being my major. Maybe what I hope is that it's a lot of working with other people create new ideas and working together.* (Sonia)

Lucy focused more on how the work should benefit people: "It has to do with like building something like a building, a bridge or coming up with a new product to help people or to relieve a problem". While the other students were hypothetical and general in their discussions about what engineers do, Bryce had a specific reference point in that he had family members who were engineers, and he imagined what they would do:

My grandpa used to do surveying and my grandma did medical stuff, so I just pictured her more in the lab with a lab coat, pouring all the chemicals and doing titrations and stuff like that. Then my grandpa just played with dirt because he was civil. (Bryce)

Notably, all of Bryce's reference points were related to the "doing" in engineering, and they focused on the technical elements of the practice.

3.4.2. Solving Problems

The students also brainstormed about the types of problems that engineers might solve. Bryce envisioned that engineers make a difference in accessibility and equity issues:

I can see engineers solving a lot of accessibility issues. That's where I want to focus on, that's what I picture, but we have most big issues solved, it's just that not everybody has access to them. I picture engineers as solving accessibility issues and making it equitable for all. (Bryce)

Later, Bryce provided a specific example about the access to clean energy (the only reference that was made by the students to "energy") for "poor" and "Black" communities, though he did not describe the role that engineers would play in helping those communities with clean energy access:

For example, I really think access to clean energy is something that's not accessible to a lot of people, especially in the poor south communities that are primarily Black communities. They have coal plants in there instead of renewable energy. They're, from the beginning, right at a health disadvantage because of the coal plants. I think access to cleaner energy will not only benefit those communities but create a more equitable system. (Bryce)

Meg again articulated an open and expansive vision of the work that engineers do, and she suggested that it could go beyond what is "stereotypical" engineering and the focus on technology:

I think they could solve any kind of problem. I don't think it would necessarily have to just be limited to technology or with what people would, I guess, stereotypically think engineers would do. (Meg)

Sonia specifically referenced the nontechnical components of engineering and community. She referred to an experience working with a community group in an introductory engineering user-centered design course as an experience that shaped her perspective:

It can be specific technical things, but also like . . . because I took the class last semester [that] is more focused on humans because we work with the blind community center, and innovations that can help people and think about the communities that you're trying to help, and what they specifically need and not just what you think they need. (Sonia)

Engineering is, in fact, people- and solution-oriented, and the students have integrated these concepts into their understanding of what engineers do. Their responses, again, hint at engineering as something more, although what that something might be is still being defined.

4. Discussion

This energy course is the first course that students take in the integrated engineering major, which is a unique engineering major where a sociotechnical approach to engineering is emphasized. Although the findings from this study are limited to a small group of students from a single course offering, the students' responses suggest that the course was successful in shifting their conceptual paradigms of engineering from a technocentric ideology towards a more sociotechnical approach. Following complexity theory in engineering education research [42,43], these results are promising for extrapolation to larger and broader student populations, and for educators who are interested in cultivating the development of sustainability-conscious engineers.

While promising, these findings also highlight that the students' understanding of the sociotechnical engineering paradigm, and the relationship between sustainability and engineering/engineers, is nascent. Their descriptions were often lofty and nebulous (i.e., "engineering can be anything"), as were their descriptions of the "why" for engineering (i.e., "making a change", or "benefitting society"). The students, who were mostly in their second year of college, were still early in their educational journey in engineering, so it is unsurprising that, developmentally, their conceptions and articulations would be at an early stage.

Despite the vagueness in their descriptions, such verbalizations hinted at the sociotechnical, and we take them as signs that our intended seeds are taking root. For example, the statement, "engineering can be anything", while nebulous, is also quite open-minded and welcoming, and it speaks to engineering being more than just a quantitative and technical profession. Similarly, we take the grasping to describe the "why" for engineering as another good sign that students are developing as engineers who are working with purpose for the good of humanity and of our planet.

Simultaneously, these students have had multiple exposure points to sociotechnical engineering, including and beyond this course, and they are in a department that is working to embody the sociotechnical paradigm in all student experiences. From this perspective, we might expect these students to be farther along on this journey. As such, these findings suggest how entrenched the dominant technocentric engineering paradigm is in our culture. For example, the students' often myopic focus on "doing" in engineering is core to the technocentric engineering paradigm and is a persistent tentacle of the dominant masculine White Western imperialistic discourse that we work to dismantle in our educational community. The students' focus on engineers as problem-solvers has elements of the "superhero" trope, and is reminiscent of the White savior complex [44,45].

The technical focus was mostly conveyed by what the students did not talk about. For example, though the students had experiences in approaching their in-class engineering analyses through the PESTLE framework, which emphasizes engineering within political, economic, social, technical, legal, and environmental contexts, their descriptions usually mentioned the technical and were largely devoid of other considerations, except for vague statements such as, "engineering can be more than technical". For example, the environment was only mentioned briefly by one student, and none of the students talked about engineers designing within these contexts.

Similarly, the student references to sustainability did not include anything they had to say about engineers and the work that they do. As such, there was an a-la-carte feel to the students' conceptualization of sustainability as it relates to engineering, as in, "you can 'do' sustainability with engineering, but do not have to; sustainability is not necessarily part of engineering". We, as an engineering educational collective, propagate this notion as we designate certain engineering courses, concentrations, and/or majors with the label of "sustainability", while others do not have the label. This choice is driven by the structure of our boxed and entrenched higher education system, which necessitates the compartmentalization and siloing of different topics and foci. An inadvertent side effect in the case of sustainability, however, is the unspoken communication that engineering and sustainability are two separate things, and that some engineers may choose to incorporate sustainability, while others may choose not to. In actuality, sustainability should be inherently and irrevocably fused into all of engineering and into the work of all engineers; it cannot be split apart. Sustainability is not a choice, but rather an ethical obligation of engineers practicing in the twenty-first century. How can we convey this critical notion to our engineering students when some can choose to take a few courses in sustainability, while others can skip it?

Moving forward, it is important for engineering education researchers to critique and analyze how sustainability discourse is both created and communicated in the engineering classroom. Nurturing and facilitating conversations about the sociotechnical nature of engineering and its connection to sustainability throughout the curriculum may be necessary as we prepare the current and future generations of engineers. Twenty-first century problems require twenty-first century skills, approaches, and practices that are only possible if the discourse around sustainability and the sociotechnical nature of engineering becomes a fundamental piece of the twenty-first century engineer.

5. Conclusions

In this study, we interviewed undergraduate engineering students after they completed a sociotechnical sustainability-focused energy course in order to explore how they perceived and communicated about engineers and engineering. While we did hear students forming sociotechnical descriptions, we found that these students were still developing their understanding and perceptions of engineers and engineering. They were also still working to integrate sustainability into those perceptions.

Our findings underscore the importance of revisiting what is seen as modern-day engineering and how it is taught. We submit that the sociotechnical approach and sustainability focus are essential to all of engineering. Moreover, students will not "get" this engineering by sampling it in some of their engineering learning experiences. Rather, doing so misinforms students that you can "do" engineering without consideration to the sociotechnical approach or to sustainability. As engineering educators, we must ensure that all of our engineering curricula embody the sociotechnical approach and integrate a sustainability focus.

Instead of encounters in isolated courses, or with only a couple of their engineering professors, engineering students likely need these pedagogical paradigms (i.e., sociotechnical engineering and sustainability) woven throughout the entirety of their engineering courses if they are to fully accept and integrate them into their own constructs about engineers and engineering. When the terms "sociotechnical" and "sustainability" are superfluous descriptors of the culturally dominant engineering practice and education because they are seen as inherent to, and inextricable from, the field, then we will have finally achieved the needed paradigm shift.

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