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Pedagogical Considerations and Challenges for Sociotechnical Integration within a Materials Science Class*

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This paper describes the creation and refinement of sociotechnical content within an introductory Materials Science and Engineering (MSE) course by incorporating principles of sustainability (i.e., social and environmental context), interdisciplinary collaborations, and best pedagogical practices. The paper uses student data from focus groups and interviews, final exam responses, and researcher and instructor reflections on the practical pedagogical realities of teaching sociotechnical modules. Our results show that students showed a greater awareness of social and environmental issues but also expressed a need to engage beyond a surface level of awareness so that they can see the direct impact of engineering decisions on people and the environment. Additionally, while many students expressed interest in incorporating social and environmental considerations into their engineering decisions, they also perceived that they would have limited power or agency to do so as newly hired engineers because they believe their employers only care about their economic bottom-line. Students struggled with seeing the value of sociotechnical content within an engineering culture that prioritizes technical over other considerations. To effectively convey the value for this content, it is important for instructors to make pedagogical choices based on best practices including assessment and reinforcement and to reframe engineering culture to embrace ambiguity and acknowledge students' feelings of lack of agency and help them develop strategies for successful careers. Lastly, we present a preliminary framework for developing and implementing sociotechnical modules within undergraduate engineering courses for those who are interested in engaging in this type of work.

Keywords: undergraduate engineering; sociotechnical; sustainability; materials science; modules

1. Introduction

Engineers are increasingly called upon to have the knowledge and skills to solve society's complex problems. This requires technical and professional skills, but also a broader understanding of ethical and social responsibility [1, 2]. Engineering professional societies reinforce this need for social responsibility through the professional obligations of their codes of ethics, which state that, for example, "Engineers shall at all times strive to serve the public interest" [3]. Likewise, in order for engineering programs to be accredited, ABET requires programs to show evidence of achievement of student outcomes including [4]:

(1) 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,
(2) 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.

These student outcomes can be difficult for engineering educators to implement into curriculum for various reasons including a strict focus on technical subjects, perceived lack of value, lack of time or resources, and instructor unfamiliarity. Educators have struggled to implement topics such as engineering ethics and sustainability to meet these outcomes, which have resulted in stand-alone lessons or separate courses that students do not see as valuable because they are not reinforced throughout the rest of the curriculum [5–8]. Compounding this problem is the perception and reinforcement of engineering as a strictly technical discipline that has led to a "culture of disengagement" [9]. Within this culture is an ideology of depoliticization and technical/social dualism, which reframes non-technical issues as not being "real" engineering and devalues social competencies [9, p. 45].

Some important research has challenged the engineering education community to change the culture within engineering to counter this narrative [10–13] and provided examples in courses throughout the undergraduate curriculum from first-year to capstone design to upper division electives [14–16]. One approach to changing the culture within engineering is by redefining engineering as a socio-

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technical discipline. Decades ago, the National Academy of Engineering acknowledged that engineering, being an integral part of society, was both social and technical and that engineers conduct their technical work in a vast integrated sociotechnical system [17]. Despite this, engineering curriculum in higher education has historically prioritized technical aspects [9, 18], and engineering educators interested in this work still need more tools, skills, and examples to meaningfully and effectively incorporate social context into their courses. The Shiley-Marcos School of Engineering at the University of San Diego was awarded a Revolutionizing Engineering and Computer Science Departments (RED) grant by the USA National Science Foundation (NSF) in 2015 to develop ''Changemaking'' Engineers by redefining the engineering canon as sociotechnical [19]. A sociotechnical canon is one in which technical/ social dualism is countered by deliberately infusing context (e.g., social, environmental) into previously decontextualized engineering curriculum or problems so that the social and technical combine and interrelate [9]. With this revised sociotechnical engineering canon, students will be able to approach problems with an expanded lens where they understand how social contexts and technical problems shape each other [20]. Previous work has been done to integrate social context into required technical courses such as Heat Transfer [21], Circuits [22], Statics [23, 24], and Materials Science [25–29].

The purpose of this paper is to describe how the instructor (SML) created and refined sociotechnical content within a Materials Science and Engineering (MSE) course by incorporating principles of sustainability (i.e., social and environmental context), interdisciplinary collaborations with postdocs (including LAG), and best pedagogical practices within engineering education. In this paper, we will describe some practical and pedagogical considerations and challenges for incorporating social context into a technical engineering course through the example of an MSE course. We begin with some background about teaching sustainability within Materials Science. Then we briefly introduce the course and sociotechnical modules including data collected. Then we discuss our results and lessons learned from reflection on the process of developing these modules for this course over three years. Finally, we conclude with a summary and propose a framework for doing this type of work.

2. Teaching Sustainability Within Materials Science

MSE classes foster students learning the real-world application of material properties for design of components, devices, and systems. This requires students to connect nanoscale physical and chemical properties to macroscale applications. Choosing the best material for a product or process often involves technical and economic considerations. However, addressing global challenges such as reducing single-use materials entering the waste stream requires incorporating more constraints into design. Materials Science educators have used the principles of sustainability as a way to incorporate contextual constraints such as the environment and society to better prepare their students to meet these global challenges [30]. Sustainability is an approach that typically balances three competing interests (i.e., economic, environmental, social) to meet the needs of the present without compromising the ability of future generations to meet their needs [31, 32]. It is essential for students to conceptualize society as a system because the three domains (i.e., economic, environmental, social) require tradeoffs and components cannot be individually optimized. For example, optimizing economic cost can result in utilizing the cheapest labor performed by the most vulnerable and exploited populations [33] or sourcing materials from conflict areas (e.g., conflict minerals such as tantalum used in capacitors) where mining the materials financially supports armed conflict, local violence, child labor, and other human rights violations [34, 35]. Thus, the optimal economic or technological solution is not always the best solution for society as a whole [30]. Sustainable solutions will have to consider other factors and constraints such as resource limitations, reusability, recyclability, energy and resource costs, greenhouse gas emission of manufacturing, material toxicity, human labor, and other geopolitical forces that affect quality of life where a material is sourced, manufactured, used, and disposed of.

Previous research has shown that best practices in teaching Materials Science include the incorporation of meaningful context where students are engaged in experiential learning focused on human and community needs, emphasizing active learning, reflection, and emphasizing design constraints such as environmental, societal, health and safety, manufacturability, sustainability, ethical, and political [36]. We decided to combine these best practices with the integration of social and environmental context using sustainability as a guide with the intention to foster greater awareness and social responsibility within our students. To integrate social content into technical courses and foster social responsibility, Vanasupa and colleagues suggest using global challenges such as climate change embedded with five guiding principles to inspire and cultivate social responsibility within

Table 1. Guiding principles used to cultivate social responsibility within students (Adapted from [37])

Number	Guiding Principle
1	*Everything is connected – engineering products cannot be viewed in a vacuum and individuals are part of an interconnected web.*
2	*The earth is a closed thermodynamic system which requires students to think about inputs and outputs on a global scale rather than a simplified one, therefore students must think about materials at all stages of its lifecycle including acquisition, manufacturing, use and reuse, and end of life.*
3	*Make responsible choices early in the life phase – it is better to prevent waste before it is created than deal with it afterward.*
4	*The sun is the earth's energy source and all energy sources can be traced back to solar energy in some capacity.*
5	*Optimize rather than maximize – rather than designing for something that is the best or the fastest, elect to optimize the design considering environmental and social impact. This requires students to look beyond a single dimension (i.e., economic) in the design phase.*

Table 2. Summary of demographics of students in ENGR 311 *Engineering Materials Science*

		Sex		Engineering Major			
Semester	**Total**	**Female**	**Male**	**Integrated**	**Electrical**	**Mechanical**	**Industrial and Systems**
Fall 2017	31	10	21	12	18	1	0
Fall 2018	9	4	5	6	0	2	1
Fall 2019	20	7	13	11	0	8	1

students [37]. These principles are provided in Table 1.

Engineering educators have described several approaches to integrating sustainability into Materials Science curriculum within single courses [38], through frameworks [39], creating elective courses [39], and creating labs aligned with sustainability concepts [40]. Sustainability has been integrated into individual classes through coursework and projects. For example, at Cal Poly State University, Vanasupa and colleagues integrated sustainability throughout their MSE curriculum by requiring readings and activities that increased students' awareness of current global challenges and how engineers can contribute to solutions, employing systems thinking through a focus on interconnectedness, and using materials selection software that helped them minimize environmental impact [38].

Engineering education researchers have documented best pedagogical practices in teaching sustainability such as using a coordinated approach across engineering curriculum to normalize sustainability concepts [41, 42], peer interactions and encouraging critical self-reflection [43], in-class active learning [44], using case studies, assignments that provide authentic learning experiences, targeted sustainability learning outcomes [45], and incorporating sustainability into assessments such as exams [42]. While teaching sustainability requires a systems thinking approach and balancing multiple stakeholders, the way it is pedagogically presented can unintentionally enforce the prioritization of different aspects over the other such as economic over environmental or environmental over social [27].

3. Class Context and Incorporation of Sociotechnical Modules

ENGR 311 *Engineering Materials Science* is a required course for Integrated Engineering majors offered every fall semester. It is the first materials science class for students at the university and provides an introduction to materials science and materials engineering design supported by Callister and Rethwisch's textbook [46]. Mechanical and Industrial and Systems Engineering majors have the option of taking this course or a materials course taught by Mechanical Engineering. In Fall 2017, Electrical Engineering majors were required to take this class. Beginning in Fall 2018, Electrical Engineers were required to take a different electronic materials class. Table 2 shows the demographics of the students enrolled in terms of engineering major and sex for the semesters where sociotechnical modules have been incorporated. Most students take this course in their third year in college.

Beginning in Fall 2017, several sociotechnical modules were introduced to the curriculum in an interdisciplinary collaboration. The instructor for this course (SML) has degrees in materials science and electrical engineering and is an engineering education researcher. Three postdoctoral researchers funded by the NSF RED grant have been valuable collaborators in this effort by developing, teaching, and/or refining sociotechnical module content using their various backgrounds and expertise. Table 3 summarizes their expertise and contributions to this course.

Creation of the sociotechnical modules focused on three of the five guiding principles described in

Table 3. Summary of postdoctoral researchers' expertise and contributions

Year	Postdocs' Expertise Area	Postdocs' Primary Contributions	Modules Described in
2017	Postdoc 1 – Anthropology Postdoc 2 – Bioengineering, User-centered Design	• Collaborated in developing (Postdoc #1 and 2) and co-taught (Postdoc #2) a new module (*Bring in Your Trash*) where students examined their own contributions to the global waste problem. • Developed and taught a new module "Mission Possible" that integrated bioengineering through a module to make material selection decisions for wrist braces for specific users within different contexts.	[26, 47]
2018	Postdoc 2 – Bioengineering, User-centered Design	• Refined and collaborated on new and existing module activities including the *Bring in Your Trash* module and the Recycling Center tour. • Brought a holistic perspective to the arc of the modules that culminated in a final student project about "Responsible Material Design" where students selected and justified a material selection decision based upon sociotechnical considerations.	[25]
2019	Postdoc 3 (LAG) – Environmental Engineering, Engineering Education	Developed and taught a new two-part module (*The Final Straw*) using the issue of single-use plastic straws to make material selection decisions that consider the social aspects of the triple bottom line of sustainability (e.g., accessibility).	[27–29]

Table 1 (i.e., 1, 3, and 5). It was critical that students recognized the interconnectedness and complexity of not only their individual decisions but the broader context of engineering (Principle #1). This would then encourage them to make responsible choices early in a product's life phase (Principle #3), which was best exemplified by the *Bring in Your Trash* module. Finally, using the triple bottom line of sustainability we encouraged adhering to environmental and social design constraints rather than just economic (Principle #5).

The most current sequence of the sociotechnical modules incorporated into *Engineering Materials Science* in Fall 2019 are summarized in Table 4. Student feedback, lessons learned, and instructor reflection were used to improve the modules during the next course offering. The *Bring in Your Trash* module was introduced in 2017 and refined for 2018 and 2019, receiving input from multiple postdocs with different backgrounds. The *Waste for Life* module was also used in all three years with some enhancements to include more calculations in the second and third years. Some modules built directly upon the expertise of the postdocs. For example, Postdoc 2 developed a bioengineering focused module in 2018 [47] and Postdoc 3 developed *The Final Straw* modules [27, 28] which focused on incorporating social and environmental content through material selection decisions of drinking straws. Some modules moved to other classes (for example, the recycling processing center tour and video used in 2018 was not used in 2019 as it was incorporated into another class). This paper will consider lessons learned from sociotechnical modules from 2017 to 2019 through the lens of the most current offering of the course (i.e., Fall 2019). More details can be found in the provided references.

4. Methods

4.1 Research Participation, Data Collected, and Analysis

To assess how students responded to the new curricular content, data was collected through required activities (i.e., homework assignments, midterm questions), researcher observations and reflections, focus groups, and individual student interviews. Voluntary research activities such as focus groups were administered and conducted by one of the postdocs or a sociology professor, rather than the course instructor, to minimize potential researcher coercion. Table 5 describes the multiple data sources collected from the students. Students were given multiple venues and class time was allocated for voluntary participation to increase potential participation and ensure students were not unduly burdened with research activities. Informed consent was obtained in class for all of these research activities before the modules were offered. Student surveys were also administered to give the instructor feedback on student attitudes towards the modules and assess learning outcomes. These surveys are described in previous work [25–28].

Focus groups and interviews were semi-structured, which involves using some structured questions to interviews but allows for participants the chance to explore issues salient to them [48, 49]. The

Table 4. Summary of social content modules integrated into ENGR 311 *Engineering Materials Science* for Fall 2019

Module Title	***Bring in Your Trash***	***The Final Straw* Part 1**	***The Final Straw* Part 2**	***Waste for Life***
Described in	[25, 26]	[28]	[27]	[25]
Offered in	Fall 2017, 2018, 2019	Fall 2019	Fall 2019	Fall 2017, 2018, 2019
Purpose of Module	Raise students' awareness of their individual contributions to the waste stream in order to design products for their end use.	Introduce students to the social and environmental context of material selection decisions through trying to quantify social impact using the example of drinking straw material selection.	Refine students' understanding of the complexity of material selection decisions and the importance of listening to vulnerable populations by focusing on case studies of users with disabilities and plastic straws.	Provide real life examples of using material science knowledge for social good.
Description	Students read a CNN article on psychology of recycling. Students collected trash for a week for class activity to think of materials with end use in mind.	Students incorporated environmental and social considerations into material selection decisions by using a Social Impact Audit Tool to audit the social impact of single use plastic straws.	Students discussed alternatives to plastic straws and used three case studies of users with disabilities to explore how, for some users, plastic is a matter of accessibility and not convenience.	Guest lecture by Caroline Baillie about how she uses Material Science for social good by focusing on waste as a resource.
Example Learning Outcome	Students will be able to explain how material choice could be broadened beyond technical properties to include aspects of sustainability and human responsibility.	Students will be able to make and justify a recommendation for change of material and/or change of material origin, production, or end of life based upon the Social Impact Audit tool.	Students will be able to describe the strengths and limitations of alternative straw materials for specific users who relies on straws as a matter of accessibility instead of convenience.	Students will be able to compare waste generation in the USA to at least two other countries and describe why it is important for engineers to consider aspects of materials beyond measurable properties such as sustainability and human responsibility.
Associated Course Learning Objective	Explain the importance of materials science in everyday life.	Given a materials design problem, evaluate the available options, select one of the options, and justify your choice.	Given a materials design problem, evaluate the available options, select one of the options, and justify your choice.	Describe how the structure of a material may be designed to produce desired properties for particular applications.

Table 5. Summary of voluntary participation data collected

Data Source	**Total participants**	**Description**	**Example question**	**Delivery method**
Focus Groups (2)	6 for 2019 7 for 2018	A 30-minute semi-structured focus group conducted on the last day of the course where students could discuss their opinions on the "Final Straw" and other sociotechnical curriculum content.	What role do you think engineers should play in incorporating social impact in their engineering decisions?	In-class, in person
Individual Interviews (3)	1 for 2019 2 for 2018	Students in the focus group were invited to participate in voluntary semi-structured in-depth individual interviews about their opinions on the "Final Straw" and other sociotechnical curriculum content. Participants compensated for their time with a gift card.	What role do you think you personally play in incorporating social or humanitarian considerations into the engineering profession?	Outside of class, in person
Curricular Data	60 total students	Homework assignments, in-class activity sheets, and responses to exam questions that include sociotechnical content.	As an engineer, if you are choosing a material for a capacitor, besides the dielectric constant, what properties or factors do you think are most important to consider and why?	In class, In person

interview and focus group protocols were developed after a discussion of researcher and instructor reflections about their observations from the classroom. Interviews and focus groups were recorded and transcribed using *TranscribeMe!* These voluntary focus group were scheduled for the last day of the course after course evaluations. Thus, the instructor was not present before or during the focus group so students would not feel pressured to participate. For research activities that required an additional time burden on students outside of class (i.e., interviews), participants were compensated with a $25 Amazon gift certificate. Further information about how focus groups and interviews were conducted is described in [29].

Qualitative data (e.g., exam responses, interviews, focus groups) were coded and analyzed thematically to find repeated meanings across a data set [50, 51]. Open and descriptive coding were used to allow for a full exploration of the data and to allow codes and categories to emerge [52]. These codes were organized into larger categories that were discussed by the researchers until they were winnowed into larger themes [53].

4.2 Triangulating with Authors' Reflections

We prioritized data that amplified student voices (i.e., focus groups, interviews), rather than our individual reflections of how we perceived their experience, to ensure a student-focused response to our efforts to integrate sociotechnical content. Thus, we utilized our own reflections and discussion as triangulation rather than its own data source. We utilized both data-source and investigator triangulation [50, 54]. For data-source triangulation, we have collected multiple forms of data (see Table 5), and included our own researcher reflections to capture our experiences and perceptions of the evolution of sociotechnical content in this MSE course. Next, we utilized investigator triangulation by having different disciplinary backgrounds, research interests, roles, and ranks.

LAG is a postdoctoral research associate with a background in environmental engineering and engineering education. At the time, she was the third postdoc hired under the school of engineering's NSF RED grant to develop "Changemaking" Engineers by redefining the engineering canon as sociotechnical [19], and worked closely with a Co-PI of that grant, SML. SML is a professor and chair of the Integrated Engineering department with expertise in electrical engineering, materials science, and engineering education. SML has over twenty-five years of experience teaching engineering classes and has written extensively about integrating social context into technical engineering courses [19], [55–58]. During the Fall 2019 semester, LAG wrote reflections after each module described in Table 4, which prompted discussions with SML. We also engaged in a formal session where we discussed: (1) How do we assess students on sociotechnical topics in engineering?; (2) How do we make something sociotechnical from two backgrounds/experiences?; and (3) What does it mean to be sociotechnical in engineering?

5. Results

5.1 Student Response to Module Content (Interviews and Focus Groups)

The analysis of the three interviews and two focus groups revealed several crosscutting themes. Students described an **enhanced awareness** for the social impact of engineering and a **lack of power and agency** to make more socially conscious engineering decisions. Additionally, students described **pedagogical and logistical challenges** to implementing sociotechnical modules. Lastly, students struggled with **valuing sociotechnical content** compared to the strictly technical content they expect in an engineering course. These themes will be described in detail below.

5.1.1 Enhanced Awareness

After engaging with the sociotechnical content, students expressed a greater awareness of social and environmental issues, especially in the 2018 iteration of the class. Some students gained an awareness of their individual impact on the global waste problem through the *Bring in Your Trash* module. For example, when commenting on how the sociotechnical modules were helpful, one student further elaborated, "[. . .] I didn't really pay attention to all of the recycling things . . . like even though they are already like categorized but like I didn't really pay attention to like put the recycling in blue can. So, after that activity, I was like more aware of putting the right thing into the right trash can" (Interview, 2018, Electrical Engineering, Male). Another student also became more aware of their personal impact by commenting on a field trip to a recycling center, saying, "I found the field trip valuable just because [. . .] we all have a sense of how much is going on, but I don't think the majority of us have been to a recycling plant like that, like a dump in person like that. So, it just kind of like puts everything into perspective" (Focus Group, 2018, Integrated Engineering-Embedded Software, Male). For another student, this awareness of individual impact came at the final sociotechnical module, *Waste for Life*. The student commented:

> "We had a guest speaker come in and talk about like when we're done with products how they're like sent to other countries and then they go in these like waste-

> lands in other countries. Which I found really interesting because I felt like our American trash was like ours; I didn't realize that it was like going to like other communities and destroying them". (Focus Group, 2018, Integrated Engineering-Embedded Software, Female).

For some students, this enhanced awareness began to stretch beyond individual responsibility to a larger professional responsibility of engineers. When asked about how the Materials Science class connected to changemaking engineering, one student responded:

> "I think that waste, for most engineers and for really normal civilians, isn't necessarily thought of as like a byproduct of what we're doing. It's mostly like we're creating and the only byproduct is like the positive impact that our innovations have. [. . .] But I think it was just interesting to have one mindset that didn't incorporate anything in terms of waste and now it seems like it's the most impactful factor in all of engineering because it's so lasting and there permanently". (Focus Group, 2018, Mechanical Engineering, Female).

While some students gained a greater awareness either of their individual responsibility or the greater responsibility of engineers, some students described a need to step beyond the awareness that was generated in the sociotechnical modules. This was best exemplified in the 2019 iteration of the class where students expressed the difference between a surface level of enhancing awareness to engaging beyond that level in *The Final Straw* Parts 1 and 2. During the focus group, students commented on how they liked *The Final Straw* Part 2 that focused on accessibility compared to Part 1 which focused on using a Social Impact Audit tool. One student stated, "I thought it was really good to think critically about different materials used for accessibility for people who, either they have a specific disability, or if they have a specific need that majority of people don't have." (Focus group, 2019, Integrated Engineering-Sustainability, Male). Another student said, "I liked the second one as well, because [. . .] we understood that plastic straws aren't the greatest for the environment, but you can't just take them away and make that the solution to it because there's a lot of people that need those plastic straws. So you can't just make decisions and not account for everyone in the public." (Focus group, 2019, Integrated Engineering-Sustainability, Male). Furthermore, when comparing the two modules one student said *The Final Straw* Part 1 was more "hypothetical and based on theory" while in *The Final Straw* Part 2 they could see how it "affected people's lives". One student mentioned that despite the focus on social impact in *The Final Straw* Part 1, they could only see how the use of a particular material "impacts the Earth, where everything is coming from, and how it's being recycled" while *The Final Straw* Part 2 "was more about choosing it for people and not necessarily as much of the environment" (Focus Group, 2019, Integrated Engineering-Sustainability, Male). Students indicated the importance of seeing the direct impact of engineering decisions on people within the sociotechnical modules and how this affects their perceptions of engineering professional responsibility. When asked to consider what the term "social responsibility of engineers" meant, one student responded:

> "I think the main thing for me is analyzing how you as an engineer have an impact on your community and being able to kind of combat that if it's negative impact and I guess feeling in touch with the community or anything that's a social responsibility of an engineer. But on the material science side also it's a little different because you can't always be in that community that you're impacting. [...] I don't think a lot of engineers realize the work they do how it impacts everything else. Because we're always thinking about – I think it's because we're always thinking about the technical side of things. We're just thinking about how we can advance technically and not really what that technological advance does outside of our little engineering level" (2019, Interview, Integrated Engineering-Sustainability, Female).

Seeing a direct impact is important to enhance social responsibility, but as the student states it can be difficult for engineers who make decisions that affect communities they are not in.

5.1.2 Power and Agency as Engineers

During these sociotechnical modules, students were asked to consider the social responsibility that engineers have. Opinions subtly shifted from the 2018 to 2019 focus groups and interviews about the importance of considering social impact. Students from the 2018 iteration appreciated the complexity of the sociotechnical issues described in the modules but prioritized technical aspects of engineering. Students from the 2019 class were more vocal about their interest and support of being socially and environmentally conscious as an engineer. Both groups, however, felt they had limited power and agency to make more socially and environmentally conscious decisions as an engineer, and especially if they were a newly hired engineer.

This perceived lack of agency permeated into their conceptions of their future career and affected their opinion of the utility of the sociotechnical modules. When asked if the class content would be helpful for the future, one student from the 2018 focus group considered their anticipated future career and responded:

> "Because of what I'm going to be doing, no. But, assume I'm an electrical engineer and I go into the

design process thinking man I'm not going to design for the dump, I'm going to design for reusability, or remanufacture ability, but then they're like, 'Oh, this costs four times as much, you can't do that.' It's like, 'Oh, okay, I guess I'm not doing that. Cool.' That was the end of all those modules and all that thinking. So, you have very little control over what you do long-term unless you're striking out on your own and doing your own thing". (Focus Group, 2018, Integrated Engineering-Embedded Software, Male).

Students from the 2019 class also shared a similar perceived lack of agency. For example, one student described how job search competition could impact the engineering decisions they made. When asked about how status as a junior engineer might affect their ability to make beneficial change, one student stated:

> "I think kind of the same as with most jobs you're there to do what they tell you a lot of the times. And it's like, oh, well, if you don't do things the way we want them, then we'll find somebody else. And I think in engineering, since there are so many people that wants [sic] jobs right now, I think that it's – a big thing is like, oh, I just need to keep my job so I'm going to do what I need to do, what they tell me to do to keep my job. And so I guess it can be really intimidating, especially if it's your first job. You don't want to go against what the boss says or argue with the boss". (Interview, 2019, Integrated Engineering-Sustainability, Female).

This issue was also examined in the 2019 focus group. The students were discussing the role engineers should play in incorporating social considerations into engineering decisions and reflected on the power an engineer had to affect people. While students agreed that engineers could and should have a positive social impact, some students could not separate their perception of a power imbalance. One student stated:

> "When you go into industry, you don't have that power immediately. You don't have very much say in what materials are being used. It's more like, "This is what we need you to do. This is how much money you have. Figure out a way to do it." And normally, you're not capable of changing social – the norms of how you're making it given that enough money and the time that you had given. So I feel like it is a engineer's role, but it's kind of hard in this age until the people that are in engineering around the country right now get to those upper roles. I don't think there's much of a say and much change right now because, again, it's all about money". (Focus Group, 2019, Integrated Engineering-Sustainability, Male).

5.1.3 Pedagogy and Logistical Classroom Challenges

Students noticed and described many of the challenges and issues in incorporating sociotechnical modules into their Materials Science class. Both cohorts of students were appreciative of and enjoyed the active and hands-on learning that were deliberately infused into these modules. This active and hands-on learning component was most obvious to students in the *Bring in Your Trash* module where they physically sifted through their own trash, worked in teams, and engaged in classroom discussion. Students also brought up that they enjoyed that these modules were different from their typical classroom experience. For example, one student said, "I feel like it's kind of like a break from what we are learning. Sometimes, where you're always just going to lectures, and looking over slides, but sometimes when you have those activities you will get your brain rested a little bit maybe" (Interview, 2018, Electrical Engineering, Male). Students generally enjoyed the sociotechnical content and how it was delivered. However, one issue they saw was logistically how this sociotechnical content was weaved into their Materials Science curriculum.

The main logistical issue students noticed was the perceived lack of continuity to the sociotechnical modules. Students mentioned that it felt jarring when switching from strictly technical Materials Science topics to what they perceived as separate and marginally related sociotechnical topics. For example, one student said about the modules:

> "I didn't see like a structure to it. It was like one day you think about it and then you stop thinking about for a really long time. And another day you think about it and then you stop thinking about it for a long time. And if you're trying to think about changemaking and like really being mindful of the impact that our decisions as engineers make in regard to waste, I feel like you can't have something like that where it's just like one time and then you don't think about it". (Focus Group, 2018, Integrated Engineering-Embedded Software, Male).

Some students commented that there should be more sociotechnical content integrated into their curriculum, but not having to devote entire class periods to it so that it would be "just a little something so that way you're thinking about it every day". Students in the 2019 focus group specifically mentioned the temporal disconnect between *The Final Straw* parts 1 and 2, which were offered weeks apart. Students described a lack of "rhythm" and how the sociotechnical content being spread out "kind of made us forget about some of the things we talked about". While they thought the modules could use better organization, one student showed some understanding for why they were offered this way. This student pointed out how class content is typically taught in engineering classrooms, which made the complex and dispersed sociotechnical content more difficult to grasp. They said, "You're taught a section at a time. So that's the way that our brains think. So if you do it as a section specifically, and you kind of just spend a week on it, then I think we'll have a little bit more of a grasp" (2019, Focus Group, Integrated Engineering-Sustainability, Male).

Finally, another issue students noticed was that there was not enough technical content in the sociotechnical modules. For example, when commenting about how the modules fit in with the Materials Science curriculum, a student responded:

> "I felt like it was kind of out of nowhere. [. . .] it's hard to picture a class where the two sort of work coherently completely. But I don't know, I think it definitely seemed like that there was a discrepancy between the two . . . I mean the activities that we talked about obviously talked mostly about . . . choosing a material but we never really talked about [the] . . . technical aspects of each material. So it did seem like there was a little bit of a disparity between the two" (Focus Group, 2019, Integrated Engineering-Sustainability, Female).

Students in the 2018 and 2019 focus groups and interviews commented about the need to improve curriculum continuity of the sociotechnical modules and how sometimes the content and delivery clashed with what they were used to. However, there were two insights from the 2019 data that were absent from 2018 data. First, 2019 students focused on the need for contextually relevant sociotechnical content that brought in real people and real voices. This was apparent in *The Final Straw* Part 2 where students were shown videos of disability advocates and were required to consider design from the perspective of three different cases of users with disabilities. Students thought this could be taken further to have a disability advocate brought to speak with them directly. On this note, students held the *Waste For Life* module in high regard because they were able to speak directly to an engineer involved in sociotechnical work. For example, one student said: "[. . .] when we talked to [Dr. Baillie] that made things really sink in. Because you're seeing somebody who has either worked in that or is impacted by something that you're designing" (Interview, 2019, Integrated Engineering-Sustainability, Female). Secondly, 2019 students (particularly Integrated Engineering students) could connect the sociotechnical modules from other classes they had taken with sociotechnical modules. This made the content less jarring for them than other students. These students mentioned specific modules and guest speakers within an integrated approach to electrical engineering class [57, 58]. One student stated, "[. . .] we did it last semester. And last semester, it felt like it came out of nowhere! But then at the end of the semester, you kind of see where those little ties are. So this made sense to me, just because I've seen it before." (2019, Focus Group, Integrated Engineering-Sustainability, Male). As described throughout the focus group and interview results, many of these engineering students had not encountered sociotechnical content or even active learning pedagogical techniques in their engineering classes before. As indicated by the 2019 focus group, when sociotechnical content is reinforced throughout their engineering curriculum, the experience may be less jarring.

5.1.4 Valuing Sociotechnical Content

For many students who are experiencing sociotechnical modules within engineering classes for the first time, another challenge is conveying value for the sociotechnical rather than strictly technical aspects. One student hinted at an awareness that separating social from technical, rather than integrating it effectively, resulted in the devaluation of the social aspects. They believed different students had different levels of motivation for engaging with these aspects and acknowledged the need for the instructor to include concepts on exams in order for some students to engage at all:

> "I think in a perfect world we would've had more time to do it. But I think the fact that like we had all this like technical material to go through was just like a big restriction, and it would be great if like they offered a class just on this, but I think like realistically people wouldn't put in the work to do it [. . .] I think a lot of it was like [the instructor] kind of had to test us on so we would show up and do them because we just wouldn't do it otherwise And so, I think it could be better if we could dedicate all this time just to it, but I don't know if people would actually take a class like that. . . I think if every day we came in and we talked about it, that would be really fun but then I'd also be like well I need to get through this material that I'm going to need for my career" (Focus Group, 2018, Mechanical Engineering, Female).

Another issue to contend with is the contradiction of complexity of sociotechnical content. Sociotechnical content was perceived by some students as too simple because it is not as difficult as technical calculations they typically encounter in their engineering courses. One student went as far as to indicate that the modules were a waste of time. He stated:

> "So, if you listen to what [another student] said you kind of hear that there was very little of value added for these modules 'cause there's not any big revelation. Like, yes, we know industrialized, first-world nations produce more waste than other nations. We knew that coming in here. We know recycling only includes some materials, we all knew that coming in here. There's just nothing . . . everything was revealed like it was this big epiphany, like we had no idea; but it was just a waste of a day for the most part". (Focus Group, 2018, Integrated Engineering-Embedded Software, Male).

It is interesting to note that despite some students

Table 6. Number of students who students freely mentioned factors related to three pillars of sustainability for a final exam question about material properties or factors

Term	Economic	Environmental	Social Factors
Fall 2019	11 out of 20 Cost	5 out of 20 Toxicity of material, recyclability of material	6 out of 20 Source of material and negative impact on community
Fall 2018	7 out of 8 Cost	6 out of 8 Toxicity of material, recyclability of material	3 out of 8 Source of material (e.g., mining)

having this perception, not all students excelled at the assessments related to the sociotechnical content. Although not highly mathematical, some of this material is quite complex and nuanced.

5.2 Student Response to Module Content (Final Exam)

In addition to directly asking students in interviews and focus groups about their responses to the modules, another way we assessed the impact of these modules was to include a question on the final exam where students could include social, economic, or environmental considerations covered in the modules without being explicitly prompted. In the 2018 and 2019 final exams, students were asked "As an engineer, if you are choosing a material for a capacitor, besides the dielectric constant, what properties or factors do you think are most important to consider and why?" Please answer in complete English sentences. (Describe at least 4 different factors or properties.)". Material choice for capacitor design was a topic explored in the course. This specificity encouraged students to think about a concrete problem rather than a theoretical or abstract material choice. This question was purposively left open-ended to see which factors students would prioritize. If students included social, economic, and environmental factors, this would show that students learned about those factors and believed they were important.

Students demonstrated learning technical and broader considerations related to material choice for a capacitor. All students were able to list a range of technical factors such as the size of the capacitor (19/20 students in 2019, 5/8 in 2018), the dielectric strength/breakdown voltage (15/20 in 2019, 7/8 in 2018), and the distance/manufacturability (10/20 in 2019, 2/8 in 2018). Most students mentioned at least one of the three pillars as summarized in Table 6. In 2018, only one student out of eight mentioned only technical factors. In 2019, six students out of 20 mentioned only technical factors. Note that economic factors were the most commonly included with more than half of the class including these in 2018 and 2019. More students mentioned social factors in 2019 compared to 2018 that may have been due to the specific modules implemented.

6. Discussion: Conveying Value for Sociotechnical Content

The challenges of incorporating sociotechnical content like sustainability have been well documented in engineering education [6, 59–66]. When instructors decide to include sociotechnical content into their curriculum, they are not only facing an already content-heavy class, a lack of time for curricular development, lack of easily available and adaptable examples, and perceived lack of expertise in the area, they also face potential pushback from both students and faculty as this work challenges the traditional culture and traditions of engineering education. As other researchers have described [20, 67–69], sociotechnical pedagogy in engineering can be difficult to implement with opposition from students who have preconceived notions of what is acceptable to include within the curriculum which are reinforced by engineering faculty. Even when there is support from leadership and other faculty interested in the work, this can be a difficult to navigate [70]. Below, we discuss key challenges to conveying the value of sociotechnical content to engineering students and offer advice on how to pragmatically approach solutions through pedagogical choices and reframing engineering culture.

6.1 Pedagogical Choices

When developing modules, it is important to follow best pedagogical practices [71, 72] and, like with any new curriculum, it can be refined over time. New modules and activities can be introduced, removed, or altered to best suit the students and the instructor. We suggest that instructors start small and build sociotechnical modules over time while documenting what worked or did not work and using formative assessment to get student feedback to improve the modules. We discuss our recommendations for considering incorporating assessment, reinforcement, and authentic voices below.

6.1.1 Assessment

Carefully crafted learning objectives and appropriate assessment are particularly valuable for these modules with sociotechnical content. A lesson learned for the instructor was the need to develop effective assessment questions related to these modules' learning objectives. She realized that if these learning objectives were only included in class discussions, but only technical calculations were included on the exams, she was sending a message to students about what was really important. In our case, we had students prepare for sociotechnical modules by integrating homework questions before and after classroom activities, and also included questions on midterm and final exams. Students with limited time and resources will look for ways to maximize their grade by making decisions on what to put time and effort into studying. By incorporating this content as part of their grade, an instructor sends a message that the content is important and worth their time [72]. Creating assessment questions can be challenging but we found that this was worth the effort. We capitalized on our interdisciplinary expertise to collaborate on iteratively developing midterm exam questions for *The Final Straw* including rubrics and sample solutions to assist in grading. We found that our most effective sociotechnical exam questions built upon the sociotechnical modules, used actual data, required students to analyze technical data, reminded them of the module content, and required students to make and justify a decision. This type of question not only incorporated social and environmental issues in materials selection, but also required students to use skills specified in ABET student outcomes such as to "analyze and interpret data, and use engineering judgment to draw conclusions" [4]. At the same time, such questions corresponded to higher levels of Bloom's taxonomy. This combination of using social context to frame a problem but requiring students to use their technical skills they are developing as engineers was particularly effective. We were able to develop such a question for *The Final Straw* Part 2 and this could have contributed to why students saw this module in a more positive light than *The Final Straw* Part 1.

6.1.2 Reinforcement

To better facilitate learning and make content 'stick', the curriculum content should be interwoven and returned to otherwise 'brain dump' occurs such as when students cram before a test and promptly forget the content [73]. By returning to material, students make stronger connections between concepts. Likewise, making connections between old and new content as well as concrete and abstract is a key to keeping students engaged in learning [74]. In our MSE class, we employed this reinforcement strategy by spreading the four module content days out throughout the semester. While students commented that the modules felt randomly placed and disjointed, they did not have trouble recalling the content on their exams nor at the end of the semester. For this reason, we plan to continue with our strategy to incorporate modules throughout the semester rather than all at once. Additionally, similar to sustainability [64], sociotechnical module content must be enforced throughout the engineering curriculum for students to value it. Likewise, as with other pedagogical techniques that are not consistently applied across the engineering curriculum (e.g., active learning), once students are exposed to this at several points in their academic career, they begin to accept it as normal and learn strategies to thrive. A single module activity such as using a guest speaker in *Waste for Life* was not enough. Students had to repeatedly engage with sociotechnical topics and see the connections not only between the modules but also between the other content they learned in the class and other engineering classes they have taken. Students mentioned previous encounters with sociotechnical content and saw connections between that content and the Materials Science sociotechnical modules. For example, students engaged in the 2018 *Mission Possible* module remarked on the connection to a course they took on User Centered Design [47] and the 2019 students in Integrated Engineering mentioned they had learned about conflict minerals in their *Integrated Approach to Electrical Engineering* class.

Seeing this type of content from multiple instructors in their discipline not only reinforced the value of the content but also normalized it within engineering. This does not mean that a practitioner has to wait for their entire department to be on board before integrating this type of content, as this would act as an additional barrier. If there are future opportunities to integrate sociotechnical or sustainability content throughout the curriculum with collaborators within or outside the department, this will provide extra reinforcement and enhance learning.

6.1.3 Authentic Voices

Lastly, we wish to emphasize that students responded more positively to sociotechnical content that emphasized concrete issues where they could see the direct impact on people. This was most clearly seen with *The Final Straw* Part 2 which the students in the 2019 focus group preferred to Part 1. Although both parts of the module considered the same issue, namely single-use plastic straws, students thought the first was more abstract and preferred the second where direct connection to people were apparent. Engineering students are not strangers to abstract and theoretical problems that they encounter in most of their math, science, and engineering courses. Given the complexity and ambiguity inherent within sociotechnical problems, seeing the direct impact of engineering decisions by listening to the people affected, such as through the video we incorporated, helps students grasp the content better. As our students suggested, bringing in a disability advocate as a guest speaker would be powerful. Given higher education's experience with remote platforms during the COVID-19 pandemic, it might be possible to bring in experts from outside the local geographic area. Valuing the voices of experts outside of technical areas is not typical in engineering culture.

6.2 Reframing Engineering Culture

In our study, we discovered that to do this work, both students and faculty must reframe how they think of engineering itself. Engineering is vaunted as apolitical and value-free using "rigor" to draw boundaries between itself from other disciplines and prioritizes technical knowledge [75]. Engineering education is traditionally decontextualized, reductionist, deterministic, with single-answer problems that must be expressed in quantitative terms [18]. This approach does not work for incorporating sociotechnical thinking. Rather we must help our students to embrace the ambiguity inherent in actual problems. Adopting a mindset of "embracing ambiguity" can help engineering students become better designers learning from the field of user-centered design [76]. When considering sustainability with its three interconnected social, environmental, and economic dimensions, traditional engineering problem-solving approaches favor the economic dimension that can often be most easily quantified. We found that even when specifically asking students to focus on social impacts of decisions, they still prioritized the economic and environmental dimensions [28]. This is understandable given the culture of engineering with its embedded sociotechnical dualism where social and technical factors coexist but are not equally valued [67]. Purely technical considerations are prioritized over social factors. Within this culture, faculty and therefore students perceive that "true engineering" is purely technical rather than sociotechnical. Engineering faculty are concerned that the curriculum will lose "rigor" with the inclusion of sociotechnical content [75] or that technical content will be sacrificed for more "fluffy" social content that they perceive is not engineering [61]. However, this distinction of social versus technical is not accurate and this perspective leads to students not being adequately prepared for the realities of industry [77].

We acknowledge that these cultural issues are deeply embedded in engineering culture and difficult to change. However, we argue that embracing the ambiguity of contextual and complex sociotechnical content such as sustainability within engineering classrooms will help students be more prepared for the complexities of engineering decision-making with the abilities described in ABET outcomes 2 and 4, and with an expanded awareness of social and environmental issues that both impact and are impacted by real-world engineering. Research has shown that successful early career engineers need to have a positive attitude in the face of sociotechnical constraints [78]. Thus, experience with such constraints in undergraduate education will help prepare students for success.

Our results from this Materials Science course echo what we have encountered in other classes where sociotechnical content was incorporated [57]. Engineering outside the classroom is contextual, complex, and must acknowledge the long-term sustainability of the design economically, environmentally, and socially. Engineering approaches and mental models (e.g., the Triple Bottom Line) in teaching sustainability have reinforced unsustainable design decisions [79]. Vanasupa and colleagues argue that the Triple Bottom Line model of sustainability implicitly treats the environment, society, and the economy as separate, interchangeable, and competing factors that leads to companies optimizing for the economic bottom line. This lack of integration, consistent with the sociotechnical divide in engineering, has long-term deleterious effects on the environment, surrounding communities, and eventually the businesses themselves. Instead, these researchers suggest an embedded systems model that reflects the thermodynamic and social reality and promotes design decisions based upon the interaction between systems. Some researchers recommend an ecofeminist approach to sustainability to refute dualistic thinking [66]. Using the guiding principles described in Table 1 [37] in combination with an embedded systems model of sustainability [79], and a sociotechnical mindset, students will be better prepared and empowered to tackle global challenges in the 21st century.

This sociotechnical dualism and Triple Bottom Line model of sustainability likely contributed to students' reported perception of lack of agency in making more environmentally and socially responsible engineering design decisions (e.g., choosing materials that do not contribute to problematic labor practices, are conflict-free, and/or do not disadvantage vulnerable communities). Most of these students had little to no actual industrial experience that suggests that this perception is part of the engineering culture that they have experienced. This is a cultural challenge that instructors will have to contend with in doing this work. To counter this perception that future employers would only prioritize economic interests in a way that benefited students' bottom line (e.g., finding a job after graduation), we developed a list of strategies that allowed for students to navigate these power dynamics over time and fit with their personal preferences [29]. Strategies range from "wait and see" to "networking" to "pro-bono work". These strategies such as "wait and see" where a student applies for relevant potential jobs without being selective of their future employer's social and environmental impact and keeps their eyes open for open positions with employers who share their values allow students to be more forward-thinking about their careers while also developing valuable professional skills. More research is needed in this area including the basis for this pervasive perception and how to help students envision and create productive and fulfilling careers.

7. Framework for Sociotechnical Integration in Engineering Courses

For those interested in this work, we have developed a preliminary framework provided in Table 7 with additional tips. The table begins with a step '0' to indicate that collaborators are helpful but not essential to begin this type of work. A lack of identified collaborators nor the challenges associated with collaboration should not inhibit instructors from pursuing integrating sociotechnical content into their courses. However, interdisciplinary collaborations are particularly valuable for providing alternative perspectives and expertise and partners for curriculum development. We have been successful with postdoctoral scholars with different expertise than the instructor as collaborators. Since these scholars were supported by an NSF grant related to this work, they were interested and encouraged to focus on sociotechnical curriculum integration. Expertise in disciplines such as anthropology, sociology, ethnic studies, environmental science, or peace studies may be particularly helpful in integrating sociotechnical content. We also recognize that support from departmental and school leadership (e.g., chairs and deans) is incredibly important in doing this work.

We conclude by offering some additional recommendations for developing and teaching sociotechnical content for engineering classes that we have learned from this work.

- **Connect sociotechnical content to students' everyday lives**: Students connect with curriculum better if it builds upon something they already know. This is true for the traditional technical engineering curriculum as well as sociotechnical. Students can bring their personal knowledge of social and environmental issues with them, which lets them better grasp the sociotechnical modules. For example, we connected the global waste problem to students' personal experience by having them bring in their own trash. We used the example of plastic straws because students were highly aware of the issue due to local single-use plastic bans.
- **Integrate sociotechnical content into students' assignments and assessments**: Build upon existing homework by combining technical calculations with discussion of social and environmental effects. Incorporate sociotechnical considerations into existing projects, presentations, and exams to normalize considerations of social and environmental impact and students considering who benefits and who pays from engineering interventions. Ensure societal context and technical content fit together so students see engineering as a sociotechnical endeavor.
- **Consider level of complexity:** Students may be unaware of some of the social impacts of everyday products they use (e.g., conflict minerals in electronic devices) and how design decisions can exacerbate social inequalities in service of economic interests and efficiency. As instructors, it is important to help students begin to appreciate the complexity of these issues without overwhelming them with guilt. Focus on empowering students to make more socially and environmentally just decisions both personally and in their professional lives
- **Sociotechnical "expertise"**: Upon first attempting this type of work, you may question whether you have enough expertise in social and environmental issues to teach students. Most engineering educators had a predominantly technical education. You can use this to your advantage as you recognize where engineering students are coming from and how to connect with them and help them engage with broader perspectives. With continuous learning, refinement, and seeking out collaborators and feedback, your expertise will grow over time. As we have seen during the recent pandemics of COVID-19 and structural racism, we need broader thinking to solve the world's pressing problems. Thus this work is critically important. If we don't do it now, when will we do it? If we don't do it, who will?

8. Conclusions

In summary, in this paper we described our efforts to incorporate sociotechnical modules into an MSE

Table 7. Framework for integrating sociotechnical modules within undergraduate engineering courses

Step	Description	Examples
0	Identify possible sociotechnical collaborators.	• Collaborating with postdoctoral research associates with expertise in areas such as bioengineering, user centered design, anthropology, engineering education, and environmental engineering to help develop, refine, and teach sociotechnical modules. • Bringing in departmental faculty such as a guest speaker to talk about their work using plastic and plant fibers to create structures for communities in Sri Lanka (i.e., the *Waste for Life* module).
1	Identify a salient course topic that has broader social and environmental implications.	Plastics are a type of polymer which have material properties (e.g., hydrophobicity, malleability) that make them ideal for widespread use by consumers. However, because single-use plastic does not break down easily in the environment and is cost-prohibitive to recycle, plastic ends up in the landfill. With decreasing landfill space, countries such as the United States export their discarded plastic to other countries who bear the environmental and social cost of dealing with the plastic. How can the material properties of plastic alternatives (e.g., silicone, paper, glass, stainless steel) reduce the environmental impact of single-use plastic and what corresponding social impacts do these material selections have?
2	Identify, add or update existing course learning objectives and/or ABET student outcome that this sociotechnical course topic aligns with.	By the end of this course you should be able to: • Explain the importance of materials science in everyday life. • Given a materials design problem, evaluate the available options, select one of the options, and justify your choice.
3	Create learning objectives for specific sociotechnical modules.	***The Final Straw* Part 2 Learning Outcomes (LOs)** • LO1: Students will be able to describe and consider environmental, economic, and social considerations when selecting a material to use. • LO2: Students will be able to describe the strengths and limitations of alternative straw materials for specific users who relies on straws as a matter of accessibility instead of convenience. • LO3: Students will be able to synthesize the needs of multiple users to create a hierarchy of alternative materials for straws.
4	Create modules by designing activities for homework before and/or after class session(s) as well as class session(s) that integrate technical content and calculations students are familiar with and social and environmental context.	Combine and synthesize your experiences with three case studies to arrange the materials into a hierarchy from best to worst straw alternatives to offer for the three individuals as a group. Indicate whether this is an acceptable plastic straw alternative for the entire group, and provide a brief reason for your ranking in the table. Below the table, EXPLAIN (using complete English sentences) why you ranked the materials the way you did. (Please type your answer.) What is **one** potential way to make one of the materials in this list more accessible to the individuals in the three case studies?
5	Include low stakes assessment for module (e.g., homework) and consider including sociotechnical questions on exams.	After plastic straw bans were proposed in California in 2018, disability advocates conducted a survey of people with multiple types of disabilities. Participants were asked to try several types of straws and report whether they recommended using them or not. Figure MT7-1 shows the results of the survey. • Given these results, which straw would you recommend for use? Why? • Why might there be different opinions for option D "stainless steel with silicone tips-bent"? Provide a general answer and then specifics including examples from at least two of the three case studies that we considered in ENGR 311. (Note: some information provided on next page for case studies.)
6	Conduct formative assessment and/or engineering education research on sociotechnical modules to get student input and improve module offerings in the future.	• This class helped me to better understand my role in designing materials with their end use in mind (1 to 5). – 1: I strongly disagree – 5: I strongly agree • How did this class help (or not help) you understand your role in designing materials with their end use in mind?
7	Refine modules and identify possible sociotechnical collaborators for the next course offering.	• The *Bring in Your Trash* module was altered to specify students do not bring in biodegradable or personally identifiable trash in 2018 and added information on Resin Identification Codes in 2019 to help students identify the type of plastic.

course and students' responses. These modules incorporated principles of sustainability (i.e., economic, social, and environmental context), interdisciplinary collaborations, and best pedagogical practices. In a final exam question that asked for students to describe important factors to consider in a design, most students authentically mentioned at least one aspect (economic, social, or environmental) beyond the purely technical demonstrating the impact of these modules. In focus groups and interviews, students described an enhanced awareness for the social impact of engineering and a lack of power and agency to make more socially conscious engineering decisions. They struggled with valuing sociotechnical content compared to the expected technical content and described pedagogical and logistical challenges to implementing these sociotechnical modules. In response to these challenges, the instructor conveyed value for sociotechnical content through assessment and reinforcement. Another challenge for instructors is to help students reframe engineering culture as sociotechnical resisting the norm to prioritize the technical and acknowledge students' perceived lack of agency and help them move towards productive and fulfilling careers.

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