

Pain and gain: barriers and opportunities for integrating sociotechnical thinking into diverse engineering courses

Abstract

This paper uses narrative analysis to study the barriers and opportunities one research team encountered as we set out to create a class assignment aimed at developing engineering students' sociotechnical habits of mind. One of the goals of this assignment was for it to be transferable across multiple course contexts, including different engineering disciplines, course instructors, level of students, and course structure. This property distinguishes it from other prior attempts at developing sociotechnical-based assignments in the literature, which have primarily focused on a single course-context.

The process of writing and implementing the assignment followed by the authors' reflection and analysis required for this paper elucidated many findings that are relevant to other efforts to integrate sociotechnical concepts into core engineering science and design courses. Specifically, we identified barriers to sociotechnical integration which include addressing the diverse needs and objectives of our courses, managing different instructor backgrounds and biases, using appropriate terminology which avoids reinforcing the dualism we are trying to address, selecting appropriate problem statements for our assignment, and settling upon the correct logistics for its implementation. Nevertheless, our work also identified opportunities presented by such sociotechnical integration. These opportunities resulted from the work of multiple instructors wrestling with the assignment together and creating an assignment that we believe fills a need in engineering education.

By collaboratively narrating our journey from conception to implementation for a single cross-contextual sociotechnical assignment and describing the lessons learned, we hope to equip other engineering educators to successfully integrate social and technical learning. This paper is also a contribution to the literature exploring why such integration is so challenging in the first place.

Introduction

American engineers are frequently educated in a depoliticized, decontextualized environment that prioritizes the technical foundation required by the profession. Devoid of the social context and full spectrum of sociotechnical considerations required for true engineering work, this practice is both poor pedagogy and an inaccurate portrayal of how engineering occurs in the world beyond the classroom [1], [2].

Engineering educators and researchers are increasingly interested in bridging this false sociotechnical divide (also referred to here and in prior work as sociotechnical dualism) and finding mechanisms for the authentic integration of sociotechnical work in the engineering classroom. Evidence for this need includes multiple sessions in recent years within the Liberal Education/Engineering and Society (LEES) Division at the American Society of Engineering

Education Annual Meeting [3]–[6] as well as other work within engineering education and technology studies [1], [7]. This prior research has increasingly accentuated that such integration is particularly important to the formation of future engineers and benefits society due to the contributions of sociotechnically adept engineers and designers. Such work has also pointed out that it is quite difficult to expand traditional student conceptions of engineering practice to include social as well as technical factors [2], [8]. One of the challenges of such integration lies in the fact that effective sociotechnical integration is likely to be implemented differently across different educational contexts, which can include different universities, engineering disciplines, course levels, and course structures (for example, engineering science vs. design courses).

Our objective is to improve engineering education so that we train students who are better able to engineer sociotechnically. To achieve this objective, the overall project from which this paper grew aims to answer the following two research questions:

- 1) What are the critical barriers and opportunities to effective sociotechnical integration in undergraduate engineering courses?
- 2) How do these barriers and opportunities change across different educational contexts, including different institutions, different course content and formats, and different grade levels of students?

In this paper, we describe the collaborative process we used to create, refine, and assess an assignment to develop students' sociotechnical integration skills across multiple courses, institutions, and grade levels. By explicating both our journey and the lessons we learned along the way, we hope to make visible critical barriers and opportunities to effective sociotechnical integration in a range of engineering education contexts.

Background

Despite the efforts of a number of researchers in recent years, many questions remain about how to illuminate the sociotechnical nature of engineering practice to engineering students. A key attribute of a student who is able to think sociotechnically is that they will acknowledge, account for, and plan for the complex interplays between social and technical dimensions of engineering across problem defining and solving phases. In this section, we describe literature relevant to such behavior.

One of the ways we conceptualize sociotechnical thinking is within the engineering habits of mind, which are defined as the values, attitudes, and skills held by engineers [9]. Prior research in engineering education has endeavored to identify engineering habits of mind and methods for teaching them. However, there does not seem to be a clear consensus about the most promising ways to address them in the classroom. This is especially true for habits of mind related to sociotechnical thinking. Lucas and Hanson [10] list six engineering habits of mind in the UK context: systems-thinking, problem-finding, visualizing, improving, creative problem-solving, and adapting. None of these explicitly challenge a core engineering mindset prioritizing technical engineering elements. LeDoux and co-authors [11] agree that a systems-thinking perspective is an important engineering habit of mind and describe a study abroad course designed to help

students answer the questions, “What is it that makes someone an engineer?” and, “What distinguishes engineers from other professionals?” Pitterson, Perova-Mello, and Streveler [12] describe habits of mind observed in a study of electrical engineering majors, but note that habits of mind in general are not well-studied in the engineering education literature.

In related work, in order to facilitate the integration of ethics into the engineering curriculum, Nair and Bulleit [13] propose identifying ethical philosophies that are compatible with the existing “engineering way of thinking” (EWT). Though we see engineering ethics as related but distinct from our interests in sociotechnical integration, we look to this work as an example of bringing together historically disparate considerations such as ethics and the technical side of engineering work.

Engineering ways of thinking were also analyzed in a case study by Godfrey on engineering culture in an Australian university that had previously undergone a curriculum and cultural overhaul. Godfrey found that the EWT design process has an emphasis on working solutions, not a singular correct solution to open-ended problems [14]. In addition, the culture of the university prioritized knowledge that could be applied, and “that abstract, philosophical concepts, such as ethics and sustainability were unacceptable to both staff and students unless taught in a practical, relevant context” [14]. Godfrey’s prior research suggests that sociotechnical engineering may come across as one such philosophical concept to be avoided.

In their 2012 book, *Engineering and Social Justice: In the University and Beyond*, editors Baillie, Pawley, and Riley worked with other researchers to present examples of bringing social justice, a key element of sociotechnical thinking that has inspired our team’s research, into engineering classrooms and fields of research [15]. In her chapter, “What counts as ‘engineering:’ Toward a redefinition,” Pawley focuses on the questions of “where” engineering is defined and “who” defines the problems [16]. Her findings point out the boundaries that are often drawn around “true” engineering work, and the challenges such boundary-defining efforts present for sociotechnical integration (since anything beyond the purely technical is usually excluded from being seen as relevant to engineering work).

Pawley’s work joins others that look at the sociotechnical divide through the lenses of gender studies and feminist critique. Faulkner, for example, points out that there is a “general penchant for dichotomous styles of thought in engineering” [8]. In sociotechnical dualism, the two sides are “deemed to be mutually exclusive,” with a hierarchy that values the technical as the more powerful and valuable of the two. The social is often “deemed irrelevant,” despite the reality that in practice, engineering involves both technical and social dimensions [2]. Faulkner also writes that engineers’ self-interest lies in preserving their roles and expertise by valuing the technical above all else, as this maintains their positions of importance and power [2], [8].

The history of how sociotechnical dualism became the norm in engineering is reflected upon in a short essay by Stevens in [26]. Stevens writes that historically, engineering distinguished itself from maintenance work by focusing heavily on the technical concepts [26]. In addition to this separation, there is also a tendency for engineering education to grow apart from engineering practice over time [26]. These two concepts – a heavy reliance on the technical and a tendency to

potentially veer from engineering practice – can work together to reinforce sociotechnical dualism in engineering education. This underlines the need for pedagogical approaches to counter such trends through sociotechnical integration. Stevens points out that students with exposure to sociotechnical concepts and design throughout their undergraduate education would be more prepared to recognize the human aspect of engineering in the workforce, which separates mediocre engineers from great engineers [26]. People are an intrinsic and inseparable part of engineering and of technical systems. This is reflected best in engineering when engineers rotate between diverse stakeholder needs and integrate different perspectives into their work. This reality can be mirrored in the classroom by a curriculum that emphasizes sociotechnical integration [26].

At the University of San Diego (USD), recent efforts funded by a National Science Foundation (NSF) Revolutionizing Engineering and Computer Science Departments (RED) grant have focused on shifting the teaching of engineering from purely technical to a sociotechnical endeavor [17]. Mejia *et al.* describe the team's efforts to develop a curriculum grounded in a critical pedagogical approach that incorporates sociotechnical considerations across courses [17]. Elsewhere, the USD team details a materials science module they developed and implemented to integrate social contexts into a technical course as a way to foster social responsibility [18]. In this activity, students brought in bags of trash and worked through a sorting exercise in a short-term class module.

As part of our team's previous work on the project described in this paper, we proposed the creation of intervention assignments that emphasize sociotechnical thinking in undergraduate engineering curricula in which "engineering students identify potential stakeholders in a current problem, as well as appreciate why the problem matters and how it can be resolved" [5]. Such interventions focus on rewriting problem statements so that the engineering work is framed by how it impacts society rather than as narrow technical problems. In creating the assignment that is the focus of this paper, we strove to incorporate these concerns by tasking students with the challenge of framing an engineering problem in a way that considers multiple, different stakeholder opinions on why the problem matters and how to approach the solution.

For intervention assignments to be effective, students must be actively engaged in the classroom. The desire to incorporate sociotechnical thinking in classrooms has strong ties to previous research on effectively engaging engineering students by Adams *et al* [19]. In fields where knowledge is quickly outdated, students need to learn how to make connections between concepts in their field and broad engineering contexts [19]. Learning these connections takes five essential characteristics, described in Adams' paper as: connections between new and old, between abstract and concrete, between understanding and applying, low-level connections and patterns rather than superficial comparisons, and instructors setting an example of the attitudes and mindsets desired in the students [19]. By making these connections in the classroom, we postulate that students will be more engaged and prepared to operate in the engineering field even after engineering knowledge evolves past the technical background they gained in their undergraduate education.

Our aim is to find means of increasing students' abilities to think sociotechnically within the traditional engineering curriculum via an assignment that is sufficiently adaptable for use in different types of engineering classes and at different universities. The aim is not to create a one-size-fits-all assignment that works in all classes for all engineering disciplines, but instead an assignment that is readily adaptable to various engineering education classroom contexts.

As described in the sections to follow, we settled on addressing the students' struggle with sociotechnical integration during the problem definition stage of a course assignment or project. We aimed to create an assignment analogous to Blank's Business Model Canvas for the LEAN start-ups [20]. Blank has created a successful model for showing students the importance of interviewing 'customers' for finding value in products or processes being developed. For the Business Model Canvas assignment, students are required to 'get outside the building' and interview as many potential customers as possible, while considering the solution space and the problem definition. This real-time feedback, constant reflection and assessment of the problem has shown to be a successful way of using interviewing techniques to tie social concepts into a project or assignment. Additionally, interviewing and having conversations is a well-documented formative assessment practice. It is a method for closing the loop in the assessment process and can be a valuable technique to give feedback to students and/or guide their instruction. Finally, interviewing is also effective in laying the initial groundwork for the kinds of stakeholder engagement increasingly necessary in engineering innovation and practice [21].

Research Methods

Methodology

This work presents the barriers encountered and opportunities illuminated by our research team as we worked to create an assignment to develop students' sociotechnical habits of mind. Because it reflects the lived experiences of an entire research team, we settled upon narrative analysis as our desired methodology. Narrative analysis "centers on the 'stories' which people generate as they seek to make sense of their experiences" [22]. Upon reflection, we realized that the process consisted of repeated attempts at sense-making with cycles of individual and collaborative work, a process that lends itself to the narrative analysis format.

To start this analysis, each of the five co-authors wrote a personal narrative describing, from their perspective, the process we followed to create and refine the assignment, and the barriers and opportunities encountered along the way. These narratives were written using a common template with prompts, though text that did not fit within the prompts was also considered in the final analysis. After the individual narratives were completed, one of us ("Professor A") used them to craft a coherent account of the team's experiences.

The five co-authors and their respective roles in the project are listed in Table 1. Note that we use the title "Professor" for all faculty members on our team, both teaching line and tenure line, without implying that this is their official university rank. Professors A, B, C, and D are all members of the academic faculty at their institutions. Professors A and B have reached the highest teaching faculty rank at their university, Professor C is an early career non-tenure track

Table 1: Research team and roles.

Research Team Member	Role	Selected Demographics
Professor A	Lead author and professor (teaching faculty) teaching the third-year course “EM,” University A	Female, white (non-Hispanic), heterosexual, cisgender, not first-generation college student, Ph.D. (Electrical Engineering)
Professor B	Co-author and professor (teaching faculty) teaching the second-year “Intro to ME,” University A	Female, white (non-Hispanic), heterosexual, cisgender, not first-generation college student, Ph.D. (Mechanical Engineering)
Professor C	Co-author and professor (teaching faculty) teaching the first-year “Projects” course in which the Interview Assignment was piloted during Fall 2018, University B	Female, Asian-American, heterosexual, cisgender, not first-generation college student, Ph.D. (Mechanical Engineering)
Professor D	Co-author, project PI and associate professor (tenure line) who had previously integrated sociotechnical thinking into a course and who collaborated on the interventions, University A	Female, white (non-Hispanic), heterosexual, cisgender, not first-generation college student, Ph.D. (Electrical Engineering)
Student A	Co-author and undergraduate research assistant, University A	Female, white (non-Hispanic), queer/LGBTQ+ identifying, cisgender, not first-generation college student, Electrical Engineering Senior student
Student B	Intervention planning workshop participant and undergraduate research assistant, University A	Female, two or more races, heterosexual, cisgender, not first-generation college student, Electrical Engineering Junior

instructor, and Professor D is currently a tenured Associate Professor. Such ranks enable most team members to take some risks with their educational endeavors. All four are female and hold PhDs in their respective engineering disciplines. Both undergraduate research assistants identified in Table 1 are also female, and both are majoring in electrical engineering.

In addition to the individual narratives, other sources of narrative were also incorporated. These included individual reflection logs, email conversations, meeting notes, and the results of group brainstorming activities. By describing in some detail the processes we used to generate the assignment and create meaning for the community, we hope to provide communicative validation [23].

We termed this approach *collaborative narrative*. Our findings are presented below, following a discussion of the institutional and course contexts for this work.

Institutional and Course Contexts

The research takes place at two universities in the Western U.S. University A is a small (<10,000 student) public university and University B is a large (>20,000 student) public university in a nearby city. Due to proximity and the fact that both universities have substantial in-state student populations within their engineering programs, the demographics of the populations from which they draw their students are similar.

Three class levels are considered within this research. At University A, a second-year introduction to mechanical engineering class (“Intro to ME”) and a third-year electromagnetics (“EM”) class are included in the research. Intro to ME enrolls around 150-200 students every semester in 3-4 sections and is substantially project-based. EM enrolls primarily students majoring in electrical engineering and is taught in a single section each semester, with an average of 40 students per semester. At University B, a first-year engineering projects class (“Projects”) is the subject of our research. The Projects course enrolls students from all engineering majors as well as some students who have not declared an engineering major. Approximately 600 students are enrolled each academic year in 20 sections of the course split between the Fall and Spring semesters. For Fall 2018, 30 students were enrolled in the experimental version of the course. Of the three courses, EM is the most similar to traditional, lecture-based engineering science courses, though prior to the research described here, it had already been shifted to include project-based learning and been redeveloped by Professor A as informed by engineering education research to include active learning.

The goal of the assignment was to devise an instrument that could be used both to facilitate student engagement with and learning of sociotechnical thinking within engineering and provide data useful to the broader research project which this work is a part of. The three course instructors (“Professors A, B, and C”), undergraduate research assistants (“Students A and B”), and a fourth professor on the research team (“Professor D”) who had previously integrated sociotechnical thinking into an engineering science course met multiple times to devise an assignment format that could be relevant to a variety of course formats and levels and to update it via a formative assessment process.

The assignment, which is the focus of this paper, is one of several data sources being used to answer the three major research questions of our project (see [5], [24] for more details on the larger research project). Note that in the narrative that follows, Student B was only involved in the initial stage of creating the assignment and did not provide a narrative for the purpose of this paper, while Student A worked to create the rubric and did write a narrative chronicling her experiences.

Collaborative Narrative – The Creation and Refinement of a Sociotechnical Assignment

For clarity, the collaborative narrative that follows is organized in rough chronological order to recount the process used to develop the assignment described. Professor A compiled this collaborative narrative from the five individual narratives written by each member of our research team. Direct quotations are used where viewpoints varied between the team members, where a team member’s identity or role is clearly relevant to the point being made, or where the text is taken directly from a source other than the narrative provided (for example, from an email or personal notes).

In the collaborative narrative, we bold the barriers and opportunities that emerged from our research. We also list these findings in Table 2 for easy reference.

Creating the Assignment

In summer 2018, four faculty members of our research group (three of the intervention course instructors (Professors A, B, and C) and the project lead (Professor D)) and an undergraduate researcher (Student B) met for a half-day workshop to craft the first assignment that would be implemented across our three courses.

Table 2: Barriers and opportunities for sociotechnical integration.

Barrier	Opportunity
Diverse perspectives and objectives of the faculty members involved	Multiple instructors wrestling with interventions across these different classes may lead to more thoughtful, purposeful sociotechnical integration that also enables students to more easily apply concepts in multiple classes, even if only taught in one
Terminology – engineer vs. non-engineer, technical vs. non-technical – may reinforce the dualism we are trying to challenge	The possibility to shift students’ views of engineering to include sociotechnical work
Selecting appropriate problem statements with consistent qualities across the courses was difficult given the diverse course contexts and student populations (year, major, etc.)	Instructor optimism and excitement to create meaningful new assignment(s) for impact their students’ views of engineering and abilities to engineer sociotechnically
Logistical considerations, e.g. <i>Who counts as a non-engineer? Can a student team divide up this assignment, or is it more fruitful to have them each work on it individually?</i>	
Student perceptions of “true” engineering work as purely technical rather than sociotechnical	
Incorporating sociotechnical content which is not commonly considered a part of the engineering canon puts extra demands on faculty, including time and energy	

The overarching goal of the summer half day workshop was to prepare one course learning activity that was suitable for implementation in all three of the classes – in other words, an activity that had the potential for broad dissemination – along with a draft assessment rubric that could be used to collect data across courses. The workshop aimed to: 1) share and evaluate current course learning objectives, 2) align current course learning objectives with sociotechnical learning objectives, 3) brainstorm an idea for a course assignment that could work with all courses (both design and technical focused) and 4) begin to create an assessment rubric for the assignment.

Throughout the workshop, it was observed that in order to achieve sociotechnical integration in the classroom, multiple stages would be required, with the course assignment and assessment rubric addressing just one of these stages. Based on the learning objectives set forth for our courses (see Appendix B), the assignment was created.

Upon reflecting on the genesis of this assignment, it is striking that each of the members of our research team had different views on what the goals of the assignment were and are. For example, Professor A stated that the goal was to create, “an assignment that would lead students in the development of specific sociotechnical-related learning objectives which we had identified for our courses [7].” She then went out to outline the learning objectives which tied to the assignment. Professor B focused on showing students the importance of creative problem-solving and “getting out of the building” to interact with others and, in turn, create “a more expansive solution space.” Professor C reflected on her prior knowledge of sociotechnical integration [25] and her prior experience challenging her students to listen contextually, “be more aware of their implicit biases, assumptions, and position of power/privilege as engineering designers and college students,” and to realize that non-engineers “have a wealth of knowledge.” Professor D stated that the goal of the assignment was to “create an assignment that could create a space for our students to think sociotechnically across a range of classes, provide data for research, and be relatively easy to adapt to different subject matter.” Finally, Student A, who was unable to attend the workshop but began to work on the assignment soon after it was initially crafted, summarized the objectives as follows: “The motivation behind the ... assignment is requiring students to view the same problem from different lenses - specifically, to define and propose a solution to a design problem through an engineering and a non-engineering lens.”

While clearly overlapping and related, the goals of these four faculty members and one student were also distinct from each other. We found this to be a **barrier** to this work: bringing together four professors with their own objectives, own perspectives, and own approaches to teaching and engineering, and working together to create a single, unified assignment about a concept as difficult as sociotechnical thinking. Such a barrier was also evident in some of the questions Professor D reported struggling with as we created the first version of this assignment. These questions included, “Was it more important for the assignment to be a teaching tool or a data collection tool (for our research questions)? Was it possible to do both well?” and “What elements of “sociotechnical thinking” did each professor want to teach in their course? Could we identify a shared set of sociotechnical learning objectives?”

And yet, as will be demonstrated in the remainder of this paper, we also saw this collaborative assignment-writing as an **opportunity**. We believe that it was the very process of working closely with peers that enabled us to create an assignment that was both effective at sociotechnical integration and transferable across diverse contexts.

Assignment Version 1

In our initial meeting, we focused on creating a space for *problem redefinition* (or at least considering how problems are defined and what factors influence problem definition), inspired by prior work in this area [25]. Problem redefinition was something we agreed had relevance across our diverse course contexts. For example, traditional engineering science courses often present well-defined, closed-ended problems for students to solve numerically, while engineering design courses often present open-ended problems for students to design creative solutions for but which often still lack social context. We felt that problem redefinition also was clearly tied to one of our emerging objectives for the course assignment (Appendix B), which focused on improving students' abilities to recognize and account for ambiguity in the problems they are working on as well as to contemplate the factors that inform the problem definition itself.

To craft an assignment around problem redefinition, we began by brainstorming a list of questions that we wanted to inspire students to think about as they wrestled with a problem statement (see Figure 1). It is interesting to note that, while we each recalled the overall objectives of this assignment differently (as described above in *Creating the Assignment*), Professor D pointed out that during our first meeting, it was “surprisingly easy to achieve consensus on [what we wanted our students to learn about sociotechnical thinking] across the different course topics and levels.” The list of brainstormed questions clarified this process for us.

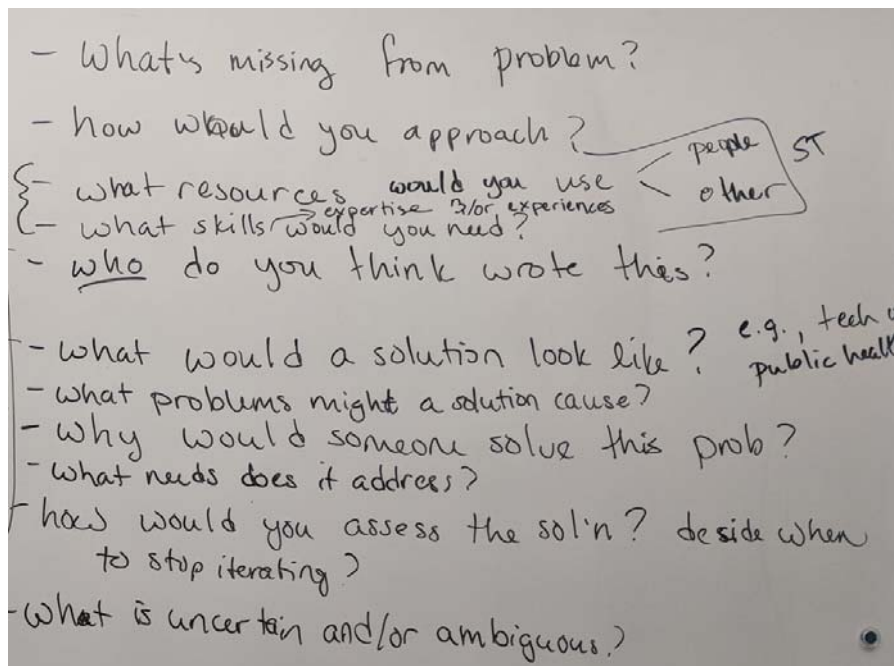


Figure 1: First workshop brainstormed list of questions for students to address in the Interview Assignment.

In hindsight, it is notable that as engineering faculty and students, our list of questions is already biased somewhat towards tangible and concrete factors, actions, and actors (who, what, where, when, how, why) rather than more abstract or ambiguous social and cultural constructs. Upon reflecting further on our process, we noticed that even a team such as ours – composed of engineers dedicated to sociotechnical integration – struggled to completely move away from some typical engineering ways of thinking.

Following our initial brainstorm, we then proceeded to categorize and prioritize these questions. A pattern emerged wherein some of the questions required the gathering of information through interviews and others required synthesizing or accounting for the information gathered. This resulted in the first version of the assignment, which was envisioned as a 1-page, 2-sided worksheet to be filled out by students in real time while talking about a problem with both an engineer and a non-engineer.

We called this assignment the “Interview Assignment,” and refer to it by this name in the text that follows. The assignment looks like the following: on the front side of the worksheet, there are two side-by-side columns. Students start by identifying two individuals (one engineer and one non-engineer) to interview for the assignment, with the two columns corresponding to the two interviews they carry out. They fill in information obtained from questioning the interviewees about their personal background before proceeding to ask them questions like how they view the problem, what resources they would draw on to develop a problem solution, and if they think the problem should be addressed at all. Note that the interviewees were initially asked to “sketch a solution to the problem.” As explained in the *Revising the Assignment* section below, we later modified this portion of the assignment so that it focused exclusively on problem definition, rather than how it might be solved.

The second side of the worksheet asks the students to begin developing solutions based on the information provided in their interviews, which culminates in writing an integrated problem statement. It also asks students to reflect on the process of pulling together information and perspectives from an engineer and non-engineer. This part of the assignment is where students can demonstrate their ability to apply sociotechnical integration to original problem statement provided.

Appendix A contains the assignment in its current form. Appendix B provides the sociotechnical learning objectives that we are attempting to satisfy, in part, through this assignment.

Student A was not involved in the initial creation of the Interview Assignment but did review the first draft of it shortly thereafter. She described being concerned at the time, “that the original draft of the assignment was too divided between social and technical. Since the intervention is supposed to combat this division, not reinforce it, [she] struggled with how to leverage the engineer and non-engineer interviews to guide students to make sociotechnical connections.” Similarly, Professor D reflected that our use of the term “non-engineer” was also of issue, writing that the fact, “that we’re even defining a knowledgeable person in a field related to the problem the student is trying to solve in the negative is problematic for many reasons.” This raises another **barrier** to this work: using terminology such as technical/non-technical and

engineer/non-engineer may serve to reinforce the very divide we are trying to overcome. Though we ultimately decided that it was difficult to address a problem without giving it a descriptive name, we remain dissatisfied with the language available.

Implementation of Assignment Version 1

Professor C piloted this assignment in the fall of 2018 in the Projects course. A number of additional challenges came to light as our team wrestled with the details of implementing this assignment. These are described in detail here and are summarized as barriers in Table 2.

As described above, asking students to rewrite standard closed-ended engineering problems to account for social context has been used in previous work to incorporate social justice into engineering core classes [26]. In our Interview Assignment, we encountered the **barrier** of determining an appropriate sociotechnical problem statement to provide to students. The different contexts of our courses made such a determination difficult. For example, in the EM course, it was easy to identify homework problems that were completely devoid of any sociotechnical context. Selecting one like this for the problem statement would allow us to achieve results similar to those of [26]. However, for the Interview Assignment, it was problematic to assign a problem completely lacking in social context, as it would not give the non-engineer anything to comment on. Providing a problem statement with obvious sociotechnical considerations would be more in line with the types of problems that are usually encountered in a design class like the Projects or Intro to ME courses. It would also likely allow for more meaningful contributions by the non-engineer. On the other hand, doing so would also potentially fail to illuminate for the students the fact that most assigned problems in engineering education have a solely technical focus. We feared that a problem with clear sociotechnical context built into it might side-step around the potential learning opportunity for students derived from writing a single, combined problem statement based on input from both interviews.

This barrier was made evident through multiple teleconferences and email threads between members of the research team and was the one that we collectively struggled with the most. For example, Student A wrote in her research notes:

The wording of the original problem statement should be considered so that both the engineer and non-engineer are provided enough information to generate solution ideas without leading their responses. One possibility is a sufficiently broad design problem, such as controlling an autonomous vehicle: an engineer might see a technical control problem, while a non-engineer such as a lawyer may consider the legal ramifications of an accident involving an autonomous vehicle.

Similarly, Professor A wrote an email at one point stating:

If we want the students to reimagine or rewrite the problem statement, we have to give them a “problem” to start with. That problem has to both have sufficient context so that a non-engineer might imagine solutions, but also has to have sufficient technical leanings so that there is room for improved sociotechnical integration. How do we write such a statement? And write it without leading the responses on either side?

It is noteworthy that each of the five members of the research team described this challenge in their individual narratives.

This barrier further came to light following the first implementation of the Interview Assignment. Professor C, who was responsible for this first implementation, described letting students decide between using problem statements that she wrote or writing their own problem statement so that it would apply to their design project. All the student groups in her course opted to write their own problem statements, but this generally resulted in unclear or vague statements. She wrote that many groups, “Had very general problem statements related to sustainability, ... topics of “energy saving” or “water conservation”, which I think led to very superficial interviewee responses. ... I did not build-in a step of looking at the problem statements prior to setting the students loose on the interview assignment.” She acknowledged that these “general/vague” problem statements impacted the “quality of their assignments.”

As the first class to pilot the Interview Assignment, several implementation details were determined on-the-fly by Professor C as students raised questions while trying to do the assignment. In the Projects class, students worked in teams of four or five students for all project deliverables, including the Interview Assignment. Each student team was supposed to conduct two full sets of interviews, resulting in a total of four individuals interviewed for each team (two engineers and two non-engineers). No requirements were established at the outset for the number of interviewers for each interview. Student teams were allowed to determine for themselves how best to get the interviews done, meaning that individual students on teams who divided the interviews up may not have received the full benefit of reflecting on the multiple perspectives.

While the Interview Assignment was scaffolded by general discussion of the engineering design loop with information-collecting from expert users as an element of the “background research” stage, there was no direct or explicit instruction about effective interviewing techniques or how best to elicit information from these experts. Interviews were conducted in-person or over the phone, depending on availability of interviewees and interviewers. Students were encouraged to think broadly to find non-engineers and engineers with relevant knowledge to their problem statements, but most students went with friends, family, or anyone who was readily accessible for an interview. Aside from a few grumblings about “another writing assignment,” no students asked for help or complained about not being able to find engineers or non-engineers to interview for the assignment.

An additional **barrier** that many members of our team reflected on following the first implementation was focused on these additional logistical decisions that came with assigning the interview. Though she was not the classroom instructor for the first pilot, Professor B summarized a couple of these issues succinctly:

Defining and interviewing a ‘non-engineer’ was found to be problematic due to the potential lack of technical expertise around the subject matter or problem statement. If students performed this assignment as a group, they split up the assignment tasks and only interviewed either an engineer or non-engineer, defeating the purpose of this assignment.

The students initially wanted to interview engineering students as non-engineers, as they were perceived to not *yet* be “true” engineers. The instructor pushed back on this, explaining that doing so would likely limit the diversity of perspectives provided. Professor C further elaborated on the limitations of student teams approaching the assignment in this way:

Many of the teams chose to “divide and conquer” so that one student interviewed an engineer while a different student interviewed a non-engineer. To complete the assignment students had to integrate these responses by discussing with one another – but there is a layer of filtering there which may have diluted the potency of the original interviewees’ responses to the questions.

Table 3 provides a summary by Professor C of the variety of approaches the student teams took to completing their interviews.

Assessment – Rubric Version 1

Student A, who led the creation of a rubric to assess the Interview Assignment, described the process as follows: “This rubric is a synthesis of the Interview Assignment, the model rubric provided by Professor A, a final project rubric created by Professor D, and information from engineering education literature [27], [28].” The goal of this rubric is to quantify and analyze the integration of sociotechnical thinking in the engineering problem-definition process. Note that this is not intended as a rubric with which to grade the interview assignment itself for class credit, though it could be used as such if desired. (However, in the following Spring 2019 semester a version of the rubric was created for this purpose for the Intro to ME course.)

Table 3: Approaches used by students in Professor C's class to complete the interview assignment.

Anonymized Team Name	Who/How did they do the Expert Interviews?
Team 1	Team had 3 women; 2 men. One woman interviewed a friend for the “non-engineer” response, a second woman interviewed her dad for the engineer response. The integration/reflection on the differences between Engineer vs. non-engineer response happened with the team members comparing their interviews, but neither interviewer interfaced directly with both interviewees.
Team 2	The two non-engineers were listed as Female, 20, and Male, 19, while the Engineer was a junior-level engineering student who also worked in the building. Only the first page of the non-engineer interviews was completed, the 2 nd page was left incomplete
Team 3	One set of interviews was done by one student; a second set of interviews was done by another student.
Team 4	Three interviews done to different sets of completion by three team members
Team 5	Two students interviewed one person each
Team 6	Four different people were interviewed, interviews completed/filled out digitally so hard to tell who did what. Only finished the front side of the interview questions – so no solutions or rewritten work!

Through the creation of the rubric, Student A provided useful feedback on the Interview Assignment itself. For example, she proposed using the assignment to provide input on students' course projects, similar to how Professor C ended up implementing it. At the same time, Student A observed that, if this was carried out, "I am not sure how well the rubric will isolate the impact of the Interview Assignment intervention specifically as opposed to the impact of multiple interventions throughout the semester."

Following the pilot implementation of the assignment, the rubric was updated in minor ways. Student A described:

In its most current form, the rubric consists of one row to assess the solution sketch based on the engineer interview and one row to assess the solution sketch based on the non-engineer interview. The next three rows analyze the student's response to the combined problem statement, including what considerations and resources are accounted for. The sixth row assessed the combined solution and to what degree students demonstrate sociotechnical integration of diverse perspectives. Finally, the seventh row analyzes students' reflections on why they created the combined solution in the manner they did. There is space for additional notes at the bottom of the rubric regarding engineering habits of mind and suggestions to improve the assignment and rubric.

The current version of the rubric is found in Appendix C.

Revising the Assignment

In January 2019, our team met again to discuss the issues experienced when implementing the first version of the assignment. Based on input from the first pilot of the Interview Assignment, we made a number of changes to the protocol of how we would implement it. For example, we discussed the fact that writing a good problem statement is difficult for students of all levels and concluded that we would try implementing the assignment with instructor-provided problem statements rather than having students write their own. We also discussed the issues with student teams dividing up the interview assignment and decided for the second iteration (Spring 2019) to have students do the assignment on their own, so that each student would be prompted to perform the process of integrating the engineering and non-engineering information/perspectives.

We also slightly modified the assignment itself. Instead of having students "sketch solutions" from engineering and non-engineering perspectives, the focus is now on re-defining the problem in two stages: first based on the two distinct viewpoints (engineer and non-engineer), and then to combine the two rewritten problem statements into a single one. We still ask students to "identify critical elements or important features of a solution to your combined problem statement", but no longer ask them to solve their rewritten problem statements. Professor C, who implemented the pilot version in her course, wrote, "I believe this will help students complete the assignment and hone in on information and problem definition rather than trying to come up with an answer/solution right away." It also alleviates pressure on students to find a correct solution, which may drive them toward more familiar technically-focused methods instead of allowing them space to think more sociotechnically.

Student A suggested adding to the interview assignment an in-class exercise in which students compare their completed interviews and answer the following question:

Compare the three problem statements that you each wrote based on the engineer's input, the non-engineer's input, and your synthesized problem statement. What are the main similarities and differences?

This addresses our learning objective related to addressing ambiguity in engineering problems through recognizing that even two engineers or non-engineers might define the same problem differently.

Discussion

As our team reflected on the experience of creating a transferable assignment to develop engineering students' ability to engineer sociotechnically, there were additional barriers and opportunities that came up multiple times throughout the process. These barriers and opportunities were usually paired together, reflecting the fact that each challenge also opened up the possibility of a positive outcome. Key barriers and opportunities have been categorized under "student perceptions and resistance" and "demands on faculty" and are described below.

Student perceptions and resistance

Engineering students come to their coursework with preconceived notions of what engineering work and engineering coursework looks like, especially as they advance through their engineering degrees. This was described as a **barrier** to this work in the narratives from multiple team members. For example, Professor A wrote that students perceive "engineering as problem-solving, and not problem-defining." Similarly, Professor C wrote:

Another struggle for [the Projects class] each semester is getting students to value communication (written and oral) as 'real engineering' – students tend to see the technical work of programming, manufacturing, building circuits, etc. as obviously 'real engineering,' but devalue other tasks including documentation and presentations. So some students felt that the interview assignment was more 'busy work' and another writing assignment that wasn't contributing directly to their projects' progress.

Altering engineering education to be more reflective of engineering practice, which includes frequent integration of the socio and technical sides of both problem and solution spaces, is one of the goals of our broader research project. So, it is not surprising that this continues to be a challenge in our work. However, our team remains confident that this is also an **opportunity**. Student A summarized this optimism in the conclusion of her narrative:

By creating an assignment that can be applied across the engineering curriculum, students have an opportunity to engage in sociotechnical problem solving from early on in their education. Since most students experience a decline in social considerations of engineering problems over the course of their undergraduate coursework, emphasizing the interplays between technical and social problem solving in traditionally technical

classes can help break down this barrier and better prepare students for their respective fields.

The possibility to revisit similar assignments over the years as students progress in their education could enable them to think more deeply about the sociotechnical nature of engineering and reinforce the message that engineering is inherently sociotechnical.

Demands on faculty

Another **barrier** that was obvious to all on our team was the demands that sociotechnical integration puts on the class instructors. Though any educational innovation requires instructor time and effort to develop and integrate, we felt that the work described here presented additional demands on faculty because it differs substantially from typical engineering coursework and indeed in the ways that most professors have themselves been trained. Professor D, who had previously done similar work in one of her own courses, mentioned the time required of faculty to do this work: “As we’re all observing, this kind of thing is hugely time intensive and can lead to burnout very quickly. Keep remembering: do less to do more (and better)” – in other words, it’s not necessary to try to integrate sociotechnical thinking throughout many aspects of a course at once, but rather to start with one or a few things that can be done well, then refine and expand on those. Professor C reflected on the importance of this in her narrative, writing, “Refocusing on the “less is more” concept helped me to channel my challenges from how to “do it all” to “how to do some of it better” in incorporating [sociotechnical thinking] into my [Projects class].”

And yet, these challenges to faculty also present an **opportunity**. Each of the three current instructors commented on their excitement about this assignment and its broader goals. Professor B said, “This assignment is exciting because if we meet the assignment goal, students are creating more expansive and more creative solution spaces through a simple interview process. This is generally a challenging feat for young engineers, many of whom have little experience in the world.” Professor C wrote that she was excited “to have students meaningfully integrate engineering and non-engineering viewpoints and realize that all problems have both technical and social aspects to their formulation as well as solution.” She saw the challenges our team has encountered as ultimately “positive signs” that we are carrying out important and necessary work, and said that developing and implementing this assignment had “definitely stretched [her] mind and challenged [her] in new ways.”

Finally, Professor D reflected that this work could lead to improved practice by engineering students and faculty, better work by practicing engineers, and development of our research team as thoughtful practitioners. She summarized:

My goal is to make engineering better, and I think a major shortcoming in engineering – and even more so in engineering education – is the devaluation of anything non-technical. I am excited about working with professors and students who understand that not everything can *or should* be solved by a differential equation. I see a real opportunity for transferability of a learning/teaching tool that can be used in a wide variety of classes and [to] challenge both faculty and students to think more deeply about the context in which engineering problems are defined and solved, as well as to challenge us to think

about how our own engineering biases (created in the culture in which we are educated and practice) shape our own thinking.

Conclusions and Future Work

In this paper, we used narrative analysis to describe the conceptualization, drafting, and refinement of an assignment and rubric designed to facilitate teaching and assessment of sociotechnical thinking in engineering. Four engineering professors, three of whom are teaching courses in which the assignment has been or will be implemented and one of whom who has previously integrated social justice into an engineering science course, worked together with two engineering students to create and refine the assignment over the course of almost a year (at the time of this writing). The assignment has been implemented in three engineering classes at two universities, two of which are project-oriented (for first and second year students) and one of which is a somewhat more traditional third year course. Due to conference deadlines, only the first implementation was used as a data source for this paper. The remaining two will be examined in future work.

Through the process of the creation and analysis of the assignment, we have identified both barriers and opportunities, many of which are paired, to this sort of sociotechnical integration in engineering courses and to the Interview Assignment in particular.

With the second iteration of the assignment currently underway, several changes have already been implemented and have taken place. However, with further analysis of the assignment in the near future, additional iterations will be made across multiple stages of its implementation. On the front-end, analysis is being done to understand the best way of presenting the assignment to classes. Logistically, should requirements on each student interviewing both an engineer and a non-engineer be given? In the examples presented to support the assignment, which sociotechnical examples do students relate to best? How is social integration tied into the engineering design process? How do we better engage students to get excited about creating better problem definitions and solution spaces? These are a few questions being asked to help guide a more fluid integration of the assignment into courses.

On the back-end of the assignment, tying course learning objectives back to the assignment will help close the loop for assessment, helping both students and faculty to clearly understand how the assignment is integrated into the course (see Appendix B for the complete list of our sociotechnical learning objectives).

It was found that students struggled to define who is an engineer and who is a non-engineer, and the latter term is still problematic in our research team's mind since it defines all possible experts from other fields in the negative. The current state of the assignment assumes that students understand the difference between these two terms. It also assumes that students know how to conduct an interview, a skill that is generally lacking in core engineering curriculum. It would be beneficial to have a module or two that exemplify good interviewing practices and techniques. This should be a requirement for the assignment along with further analysis of types of interviews that are most effective.

The project that is the foundation of this paper is ongoing, and future work will formatively assess the assignment as it was implemented in the second and third year courses (Intro to ME and EM, respectively) during the Spring 2019 semester. Data will also be collected from all three courses during the remainder of the project's duration to better understand the assignment's ability to influence the development of sociotechnical thinking among engineering students. By examining this influence within different types and levels of courses at different universities with different professors, we strive to create recommendations for transferability of the assignment to the broader engineering education community.

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Appendix A: Current Interview Assignment

Prompt	Engineer Response	Non-Engineer Response
Gender/Age:		
Relevant Expertise:		
1) Why would you solve this problem? What needs does it address?		
2) What resources are needed to solve the problem, including people (with specific skills, expertise, and/or experiences) and non-human resources?		
3) What would a solution look like? What problems might a solution cause?		
4) How do you decide if your solution solved the problem?		
5) What is missing from the problem? What is uncertain and/or ambiguous?		

Now rewrite the original problem statement and list critical elements of a potential solution based on the information offered by the Engineer vs. the Non-Engineer:

	<i>Engineer</i>	<i>Non-Engineer</i>
Rewritten Problem Statement		
List critical elements or important features of a proposed solution to this problem.		

Finally, combine both of the rewritten problem statements above to generate a single final problem statement:

Identify critical elements or important features of a solution to your combined problem statement:

What from the interviews, your values, and your experiences motivated the ultimate changes from the original to the final problem statement and/or elements of a solution? Comment and explain.

Appendix B:

The sociotechnical learning objectives for the intervention courses are as follows:

1. (A) Identify and account for both technical and social considerations in your approach to a discipline-specific problem or design.

(B) Recognize ambiguity and uncertainty in engineering problems and account for it in your proposed solution.

2. (A) Explain the strengths and limitations of diverse forms of knowledge for defining and solving engineering problems.

(B) Work with and value people who define problems differently than you do or who possess different expertise (different types of engineering, non-engineers).

Appendix C:

	0 (non-existent or requires major changes)	1 (incomplete or poorly implemented)	2 (well addressed)	Quotes/notes
This rubric is intended for to assess pg. 2 of the interview assignment. It focuses on the student's work accounting for the responses they received during the interview in both rewriting the problem statement, sketching a solution, and reflecting on what from the interviews led to any changes in either the problem statement or their potential solution.				
Solution elements (engineer)	The solution offered by the student is incomplete or does not consider the information in the engineer's interview.	The solution weakly attempts to address the considerations raised in the interview.	The solution thoroughly addresses the considerations from the engineer's interview. Any information identified as missing or ambiguous is supplied.	
Solution elements (non-engineer)	The solution offered by the student is incomplete or does not consider the information in the non-engineer's interview.	The solution weakly attempts to address the considerations raised in the interview.	The solution thoroughly addresses the considerations from the non-engineer's interview. Any information identified as missing or ambiguous is supplied.	
Rewritten problem statement (Socio-Technical)	Problem definition regurgitates the prompt and shows no signs of sociotechnical integration nor accounting for the diverse perspectives of the interviews.	There is evidence of sociotechnical thinking, but it is unclear or poorly related to the design problem. The student included few or only broad points raised by the engineer and non-engineers' responses.	Clear, concise articulation and analysis of the design problem that incorporates multiple perspectives and draws from both the engineer and non-engineer interviews.	
Relevant considerations addressed	No needs or only technical needs of the problem are accounted for.	Only superficial or poorly related sociotechnical needs are considered.	Sociotechnical needs are thoroughly explored and defined for the problem.	
Resources required	No or very few resources are considered to address the problem statement.	Superficial or poorly related social and/or technical resources are used. The student overemphasizes either the social or the technical, and lacks sociotechnical integration.	Sociotechnical resources are well defined and fully integrated. The problem statement provides any missing or ambiguous information.	
Combined solution elements (sociotechnical)	The solution elements offered fail to account for one or both of the interviews, OR the combined solution lacks sociotechnical integration.	The solution draws on both interviews, but only partially. It does not account for all the responses given, or discounts one or both of the perspectives.	The elements listed span the sociotechnical solution space. They address the combined rewritten problem statement.	
Reflection on changes [1, 2]	Response is descriptive, merely reporting changes with no attempt to provide reasons (I did x).	Descriptive reflection provides reasons (often based on personal judgement), although only in a reportive way (I did x because y). OR includes dialogic reflection, a form of discourse with one's self, mulling over reasons and exploring alternatives (I wonder...? perhaps ...? maybe...?).	Critical reflection takes account of the socio-political context in which events take place and decisions are made (roles, relationships, responsibilities, gender, ethnicity, etc.).	
Additional notes on students' engineering habits of mind reflected in their responses (qualitative)				
Additional notes on 1) changing the assignment and 2) improving this rubric				
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