Faculty Interpretations of Sociotechnical Thinking in their Classrooms: Techniques for Integration

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Introduction

Engineers consider both social and technical elements within the problem spaces in which they work [1] - [3]. Yet, engineering education often better prepares students to address technical issues within well-defined technical problem spaces, with relatively less emphasis placed on social or sociotechnical elements [4] - [6]. Traditional technically-focused curricula might therefore foster the habit of solving fully-formed problems that require no problem-definition stage including community and other stakeholders [5], [6]. This disparity can lead to negative consequences for the profession and society (for example, suboptimal solutions) as well as for engineering professionals, who may feel ill-prepared to address sociotechnical elements of their professions [3]. For example, Cech found that engineering students become more disengaged with public well-being during their time in engineering programs, suggesting that these programs' separation of technical and social impact students' impressions of their own futures as engineering practitioners [7]. A key element of our research is that new concepts are therefore needed to help engineering students develop sociotechnical thinking, or the ability to identify, address, and account for "the interplay between relevant social and technical factors in the problem to be solved" [8] (p. 1). For a more in-depth motivation of the need for sociotechnical integration in engineering education, we refer readers to [8].

Developing engineering courses that address sociotechnical thinking can be challenging, especially for faculty who were themselves trained in more traditional, technically-focused curricula. Some faculty within the U.S. have integrated sociotechnical thinking or similar concepts within their classes, though the practice is not widespread. For example, Huff [4] and Johnson, Leydens, and Moskal [9] have augmented engineering classes with social justice concepts, and Riley [10] and Leydens and Lucena [6] have published books that can be used as a guide for doing so in many disciplines. A consideration of "sociotechnical" from a human organizations perspective is described by Subrahmanian for a design engineering class [11]. Engineering has been introduced as a sociotechnical process in a new introductory class described in [12]. Hoople and Choi-Fitzpatrick have recently published a new text designed to foster sociotechnical integration into engineering classes [13]. Other examples exist, but such cases do not represent the bulk of engineering education within the U.S.

As evidenced by these programs, sociotechnical thinking is gradually emerging as an important theme within engineering education. More faculty are seeking to implement these concepts in their classrooms. In this paper, we therefore seek to share insight from our team's experiences with sociotechnical integrations and our perceptions of the impacts of these integrations on our students, including how we can use our experiences for formative classroom purposes.

This paper presents the results of a qualitative analysis of faculty reflection logs written by two instructors who implemented sociotechnical thinking in their classrooms. As has been argued by Brent and Felder, writing and thinking, as is required for these logs, provokes thoughts and observations that would otherwise be lost [14]. Faculty reflection logs may therefore offer a formative tool for deepening instructors' understanding of their students' sociotechnical thinking. In addition, the insight gained from analyzing these reflection logs can serve as a guide to other faculty looking to implement sociotechnical thinking in their classrooms and curricula.

The research presented in this paper is focused on the following question:

> *RQ1. In what ways do faculty share similar and different insights with respect to the integration of sociotechnical thinking within their engineering classes as reflected through faculty reflection logs?*

Methods

For this paper, we analyzed data collected from faculty reflection logs written by two engineering professors at a public university in the United States. The research was reviewed by our university's Human Subjects research review board and all data collection and analysis was conducted according to the resulting protocols. The faculty reflection logs cover two different classes of the same university over two semesters each, Spring and Fall 2019, for a total of four faculty reflection logs. In some cases, these logs refer to prior faculty reflection logs created by a faculty member at a nearby university, University B. Each class was taught by the same professor for both semesters; we call these professors Professor A and B, as shown in Table 1. Both are part of the broader research team and co-authors of this paper.

Table 1: Research team and roles.

Research Team Member	**Role**	**Selected Demographics**
Professor A	Co-author and professor (teaching faculty) teaching the second-year "Intro to ME," ("Class A"), University A (faculty reflection logs are analyzed for this paper)	Female, white (non-Hispanic), heterosexual, cisgender, not first-generation college student, Ph.D. (Mechanical Engineering)
Professor B	Professor (teaching faculty) teaching the third-year course "EM," ("Class B"), University A (faculty reflection logs are analyzed for this paper)	Female, white (non-Hispanic), heterosexual, cisgender, not first-generation college student, Ph.D. (Electrical Engineering)
Professor C	Co-author, project PI and 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)

Professor D	Instructor (teaching faculty) teaching the first-year "Projects" course ("Class D") in which the Interview Assignment [15] was piloted during Fall 2018, University B (faculty reflection logs are not analyzed for this paper)	Female, Asian-American, heterosexual, cisgender, not first-generation college student, Ph.D. (Mechanical Engineering)
Researcher E	Lead Author and graduate research assistant, University A	Male, white (non-Hispanic), bisexual, cisgender, not first-generation college student, M.S. (Mechanical Engineering)
Researcher F	Co-author and undergraduate research assistant, University A	Female, Hispanic, gay, cisgender, not first-generation college student, undergraduate Chemical Engineering student

Professors A and B were provided with optional suggested prompts (see Appendix) by Professor C, who had previously written such logs for sociotechnical integration in her course for an earlier project. In general, Professors A and B wrote in their faculty reflection logs about once every week and a half on average. The entries varied widely, with many remarks about how the class was going in general but also how effective certain sociotechnical integration was.

In April-June, 2020, the co-authors of this paper analyzed the four faculty reflection logs using an inductive analysis model as proposed by [16]. Using this model, which is similar to grounded theory [17], we reviewed the data for more general domains, then themes, and finally created a master outline that expressed relationships within and among domains. Each of the four faculty reflection logs was coded by two or three of this paper's co-authors using the NVivo qualitative research software using an open coding method, where each researcher began by independently defining nodes of interest to the research question RQ1. Researchers then analyzed the additional logs assigned to them by starting with their first codebook, adding to it as they deemed necessary to understand the logs and answer the research question. Each researcher then summarized his or her findings in the form of individual Analytic Research Memos (iARMs) containing domains and themes relevant to each faculty reflection log. After each team member had completed his or her iARM, we met (virtually due to COVID-19) to discuss our findings, seeking elements of both agreement and disagreement. Over the second half of 2020, we compiled these iARMs into a single consensus ARM (cARM) that served as the master outline from which this paper was written. All of the findings can be traced back to quotes in the initial faculty reflection log data, some of which are included in the Findings section of this paper.

Institutional Context

University A, where faculty reflection logs from both classes analyzed in this paper were taught, is a small (<10,000 student) public university in the Western U.S. The first class (taught by Professor A) is defined as a project focused introductory course into mechanical engineering that enrolls around 150-200 second year students every semester in 3-4 sections. The second class (taught by Professor B) is a single section electromagnetic based class for 30-60 students. It is composed primarily of third year electrical engineering students.

<u>Sociotechnical Integration Examples</u>

Professors A, B, and D used a number of different techniques to integrate sociotechnical thinking into their classes. In this section, we describe a few examples to help the reader understand the findings in this paper. We refer readers to our project web site [18] for additional examples and information.

Professor A used a real-world example of the iBill, the talking banknote identifier, which was created by the US Treasury after it was ruled to discriminate against blind and visually impaired individuals due to the fact that US bank notes are all the same size and the numbers are hard to read. The US Treasury had to distribute free currency readers to eligible individuals at a significant cost. In this example, it is clear that the design of the iBill was not human centered or universal; in other words, it did not exist in an effective sociotechnical solution space.

Professor B integrated sociotechnical thinking into her entire course using a set of, “anchors,” including relating it to the National Academy of Engineering’s Grand Challenges. As part of the Grand Challenges discussion, she helped the students to understand what was missing from the list of challenges, who benefited, who suffered, and who was left out from the list-making and solution spaces.

Processor D used two real world examples, the Boulder rubber duck race and the, “Dutch reach” car door example as anchors in her class, which is part of our broader research but not explicitly included in this paper. In these examples, it was very clear that students tended to look for technical solutions to the motivating problems; however, the most simple and easy to implement solutions were socially focused.

All three professors worked together to develop and implement a transferable assignment involving interviews outside of the classroom that is further described in [15]. This assignment was used to help students understand how sociotechnical thinking can expand the problem definition space and lead to more creative solutions. In all three classes, students interviewed people with relevant knowledge for various real-world examples relevant to their class.

Professor B also followed up the interview assignment with reflection opportunities. Reflection opportunities were incorporated into this class at the individual, student team, and class discussion levels, for example debriefing the interview assignments in teams of three within class using instructor-provided prompts and then discussing as a full class. In her faculty reflection log, she described a couple of these reflections:

> "I asked questions like, 'What surprised you that you heard from the engineer or non-engineer?' and, 'How did you decide that your engineer had relevant expertise to the problem? Non-engineer?'" (19 Sep 2019)
>
> "In class today, I had an exercise in which the students were asked to critique, as a group, written motivations for engineering work. The assignment began with the following text: When presenting the motivation for your work, you are asked in your [Class B] project to go a step beyond the standard reasons that we undertake an engineering task (because it will improve health, because it's cool, because it will save money or save the environment). Rarely is engineering problem-solving so straightforward. The questions below (from Baillie et al., 2010) can help push us that extra step:
>
> - In the short and long terms, who benefits from this engineering design, models, or Grand Challenge, and how?
> - Who does not benefit?
> - Who is constrained and how?" (8 Nov 2019)

Additional sociotechnical integration examples can be found at our project web site [18].

Findings

Our inductive analysis method led to several findings that can help to illuminate the integration of sociotechnical thinking into engineering courses. In this section, we describe the key themes we discovered in the data as they emerged, providing a summary of our themes and domains at the end of the section.

The Relationship of Motivation, Engagement, and Receptivity to Sociotechnical Integration

Motivation and engagement are key parts of both effective teaching and learning [19]. For students, motivation can be described as a drive or desire to learn. Motivation leads to engagement in the classroom as students that want to learn will be more willing to interact with the class. Students that are positively engaged will remember the content better and enjoy learning more as well.

Our data led to a key theme at the intersection of motivation, engagement, and receptivity for both the faculty writing the logs and their perceptions of such in their students. This theme includes three domains that will be described in this section with supporting data: the importance of motivation to promote engagement, generating motivation, and the impact of engagement on receptivity.

The Importance of Motivation: Engaging Students and Faculty

Motivation can increase engagement in the classroom. When people are motivated in a course, they will be more open to discussion and being engaged. Additionally, since they build off each other, student engagement and faculty engagement are intertwined in a positive feedback loop [20].

One of Professor A's entries supports the idea that faculty engagement is linked to student engagement. On March 19th 2019, she wrote:

> "The lecture today was very engaging and interesting for the students, having students ideate and interact with each other, constantly moving and thinking. Hopefully this momentum continues even though the semester burnout is at a maximum and spring break is only a few days away. I am hoping to keep the students engaged with levels of excitement high, especially for the interview assignment." (19 March 2019).

Generating Motivation for Students and Faculty

The faculty reflection logs included a substantial focus on student motivation. This is obviously important, but faculty motivation is also crucial to sociotechnical integration. As the goal is to improve motivation and receptivity, the question that follows is, "How can we encourage intrinsic and/or extrinsic motivation for both students and faculty members?"

- This work uses **intrinsic motivation** to refer to an internal inherent desire. If someone wishes to perform an action or learn about a concept with no external factors, then they are intrinsically motivated. In the case of a student, if they are joining a class with content they already wish to learn more about, they are intrinsically motivated.
- In comparison, **extrinsic motivation** is an external push or guide to be interested. If someone would receive a reward (or avoid a punishment), they may be invested even if they are not personally interested in the concepts or actions. In the case of a student, if they are joining a class with content they care less about, they still may be extrinsically motivated to earn good grades or avoid losing a scholarship, for example.

In the data analysis process, we discussed the ways in which the faculty reflection log data showed both intrinsic motivation (one of our goals for sociotechnical integration) as well as extrinsic motivation. We also agreed that student evaluations (and perceived pushback) are an important extrinsic motivator for professors, with an example below from Professor B.

> "But more importantly, I think my course evaluations from the spring (with a few particularly negative remarks about the sociotechnical integration) are constantly in the back of my head. I had this discouraging train of thought a week or so ago, where I convinced myself that I would have much higher course evals – and less work for myself! – if I hadn't flipped the course, and wasn't trying to incorporate sociotechnical habits of mind. I feel like I'm constantly trying to do too much in this class, and, as one student said on the course evaluations, "Changing the world one EM lecture at a time," (something the student faulted me for). It's hard to put student opinion out of my mind, especially since I feel like I used to really be valued by the students (and now I feel like I'm constantly having to sell them on the pedagogical methods or assignments that I'm using). Anyway – student evals, man." (12 Sep 2019)

Professor B was intrinsically motivated to improve her class in several ways (flipping the class, incorporating sociotechnical thinking) but found the extrinsic motivation of student evaluations at odds with her intrinsic motivation. Similarly, students can be intrinsically motivated by sociotechnical integration while at the same time feeling a tension that their interests don't really count as engineering. As an example of this tension, Professor B wrote:

> "One student said his engineering expert brought up a really great environmental justice question – about the fact that power lines are more often buried in middle/high-income neighborhoods, and overhead in lower income neighborhoods. I loved this point – but then the student got a little bashful, and mumbled something about, "But that's not really relevant here – I just found it really interesting." (No!! It is relevant – that's the whole point!)" (19 Sep 2019)

In this case, the student appears intrinsically motivated by the sociotechnical aspects of the class but appears to have been concerned that an extrinsic factor (their impressions of the engineering profession) was at odds with their interests.

Student Engagement Leads to Receptivity

The faculty reflection logs indicate that engaging students in fruitful and rich discussions leads to both engagement in the classroom and with regards to each other and the topics. If students are engaged, it also leads to increased receptivity to the classes' content (including sociotechnical thinking). If done correctly and if the topic fully engages students, these discussions are very powerful tools. Student engagement and student receptivity also work together to improve sociotechnical learning. Students need to be engaged in the conversation to hear, but they also have to be receptive to listen and to create a lasting impact.

The faculty reflection log data indicates that students tended to engage well and be receptive to the interview assignment, for which they spoke to engineers and non-engineers [16]. According to the faculty reflections, this assignment appears to be effective for helping students identify the differences in social and technical thinking and prompting reflection on their integration. More importantly, students retained and accepted the information well because they were not led to an answer directly by the professor but rather found it organically via their own engagement, as observed in the quotes from Professor A's faculty reflection logs:

> "...I was excited to hear that a few student groups pivoted due to their interview assignments! YES! It seems like some of them actually took the time to do the assignment and took the feedback seriously! Additionally, I had two groups specifically state that they found the interview assignment very 'powerful'. They mentioned that it was intimidating and that they learned a lot from it. Other students stated that they gained several ideas from the interview assignment..." (4 April 2019).

> "Additionally, since the rest of the semester is focused on student final projects, I am starting to hear the verbal feedback about the interviews from students. In fact, I had some students state (their project was to create a new derby car track for [another class in the program], 'how are these interviews supposed to help me and what is our problem statement'. After the interviews, these students stated, 'the interviews really helped us with our track design and our problem statement. I did not realize that different people

would want various features integrated. For instance, storage came up, a fun factor, as well as a business model for actual manufacturing the track." (15 Nov 2019)

The interview assignment was taken further in Class B when it was followed with an open discussion. The faculty reflection log data suggest that the open discussions were found to be effective as students would find similar results, on their own and independently. This allowed for students to construct the solution from each other organically and hear the outside perspective from not only their own interviewees but the interviewees of other students. Professor B wrote:

> "This discussion was especially rich- I had to cut them off! The students made comments like: I slightly biased their answers by saying the health impacts were negative. An engineer-turned-doctor a student interviewed said that sometimes radiation can be a positive thing (like in reducing the likelihood of MS)." (8 Feb 2019).

The faculty reflection log quotes in this subsection make visible the importance of intersection among motivation, engagement, and receptivity. These concepts are inherently important and related, in that student motivation impacts faculty motivation and student engagement, and that engaged students are receptive to the concepts shared in the classroom.

<u>Successful Techniques for Sociotechnical Integration in Class</u>

Ideally, educators would have infinite time and energy to integrate sociotechnical thinking and other concepts they prioritize into their classes, but of course there are limitations. Realistically, there is only so much time that can be spent on each class. When deciding on tradeoffs, it is wise to consider what methods or concepts provide the biggest benefit per time invested.

In this theme, we mined the faculty reflection log data for sociotechnical integration techniques that are realistic and give the largest benefit for the smallest effort. The data suggest that the domains within this theme can help to guide sociotechnical integration in other classes.

Relatively Small Integrations Throughout the Semester

Our data suggests that a number of relatively small integrations (which may also be easier for faculty than a few larger ones) has the potential to have a large effect on the students through the course.

Time in semester impacts the effective level of sociotechnical integration into the class. Busier times of a semester can lead to students and professor focusing more on workload and stress, and less integration, as seen in the quote from Professor B:

> "I am struggling to fit in sociotechnical integration until this second unit of the class. One of the focus group students last semester pointed out that the integration lessened as the semester went on, and I completely agree with that. And yet, it's hard! I have virtually no time for course prep this semester. I should have prioritized course prep/redesign of [Class B] over the summer (with an eye towards sociotechnical integration), and am not sure why I did not." (11 Oct 2019).

With the large effect of a small integration at the start, professors may find it easiest, and still effective, to integrate sociotechnical concepts via a few, “anchors,” - or specific examples that could be returned to multiple times - throughout the class. Notably, they should also attempt to start the class off with some sociotechnical integration-based assignment to allow students to start seeing the value of sociotechnical thinking from the beginning, which can even then allow them to observe when it is missing later in the semester.

Integrating with Real World Examples

Difficulties getting student attention can negatively impact faculty engagement and receptivity. As such, ideal solutions were found to be ones that are easy to create and allow for open engagement or discussion, which may require less effort and time to produce. Professors can open the door to sociotechnical thinking with an assignment (providing some extrinsic motivation) that leads to exploring the space of the real world in an open way. This lets students find things that interest them and to discover the importance of sociotechnical integration. This was observed by both Professors A and B, respectively, in quotes from previous sections of this paper repeated here.

> “...Additionally, since the rest of the semester is focused on student final projects, I am starting to hear the verbal feedback about the interviews from students. In fact, I had some students state (their project was to create a new derby car track for [Class A]), ‘how are these interviews supposed to help me and what is our problem statement’. After the interviews, these students stated, ‘the interviews really helped us with our track design and our problem statement.” (15 Nov 2019).
>
> “This discussion was especially rich- I had to cut them off! The students made comments like: I slightly biased their answers by saying the health impacts were negative. An engineer-turned-doctor a student interviewed said that sometimes radiation can be a positive thing (like in reducing the likelihood of MS).” (8 Feb 2019).

Through these statements, it can be seen that using real world examples is a potentially useful way to motivate students to think sociotechnically, though past research has shown that care should be used since real world examples are not always sociotechnical [21]. Real world examples do allow for easier classroom integration because instead of creating a limited and explicit box for students to explore you can ask a question and let them discover it on their own. This also will improve their willingness to understand the content. Hearing this sociotechnical thinking from more than one-person (perhaps with a classroom discussion after) crosses ideas and shares experiences. However, it's important to be mindful that real world examples incorporate ambiguity and open-ended solutions that are often less familiar to students. This ambiguity is considered in the next subtheme.

Difficulties of Ambiguity or Open Problems

Many engineering class assessments are based on decontextualized problems that are very well defined and have a specific, single correct answer. This process is effective for grading but has obvious weaknesses since “real world” engineering problems tend to be inherently complex and open. In general, both the professor and students wrestled with ambiguity in open problems vs.

these more traditional closed problems. Open problems may be easier to put in place for a professor, but conversely may be more difficult to grade. In addition, pushback from students against ambiguous or open assignments may have a disproportionate impact on the professor, leading to reduced engagement or additional feelings of frustration. They also can have a negative impact on students who are primarily motivated by their grades and sometimes, "poorly defined," (i.e., open) questions can feel threatening. If a student becomes unnecessarily frustrated it can lead to a lack of engagement, pushing back, and being unreceptive, which was observed by Professor B:

> "The reason I'm bringing this up now is that, even in an assignment that looks purely "technical," I had one student who was visibly upset about the assignment. He was nervous about the next day's test and possibly just having a bad day, but also seemed to be reacting to the ambiguity of the assignment. He went so far as to say, "I don't know why we're doing this right now." (Implying – I don't know what solar cells have to do with electromagnetism, or why you're making us do this assignment.) When I justified it by saying that modeling skills are an important outcome of this class and an outcome that would also be tested the following class, he said that yes, he had looked at the practice tests from the previous semesters – "… and they were a lot more close-ended than this assignment." (Which is true – I try to provide a little more structure for the tests, because – though I want the students to be adept at this skill of applying abstract concepts in concrete ways, I know it is also a hard one.) This student is otherwise a strong student who is pretty willing to do whatever I ask him to do, so his resistance and discomfort were striking." (1 Nov 2019).

We therefore recommend attention to student stress levels and motivation, as well as providing adequate support and considering high and low stakes environments, when incorporating more ambiguous sociotechnical assignments. Additionally, by 'bringing ourselves to the table', the next theme explored, it could help show that stress and social hurdles are a real part of life and problem solving and a shared experience for both professors and students.

Creating an Emotional Connection by "Bringing Ourselves to the Table"

Professor B made some powerful statements about bringing our whole selves to the table in our teaching and learning and how doing so seems at odds with dominant engineering culture. In comparison to the often highly technical, decontextualized engineering classroom, the real world is sociotechnical. Professor B proposes that bringing in the human element will therefore help foster a learning environment that considers the social and technical sides of the engineering process. Is there an opportunity for, "bringing ourselves to the table," to shape what, "counts," as engineering?

> "We, as engineering educators, draw very clear, hard lines around what "counts" as engineering. It is only the technical. It is only the things which do not include emotion. It is only people who fit a certain mold, including those who can "hack it" and don't ever have "life" events that arise (like a breakup with a girlfriend or loss of a family member or financial hardship) during the course of their engineering work or class. And when we send this message – that students can only bring one part of themselves (the cool,

> calculating, black-and-white-seeing side) to their engineering work, we are also telling them that everything else about them – who they are as people, what they value, the types of problems they want to solve, the role of social, creative, artistic, environmental considerations – doesn't matter." (11 Oct 2019).

> "One important conversation that I did make time for last week was the discussion around mental health and students' ability to be their "whole person" in my class and hopefully in other classes at [University A]. The conversation is always awkward and I'm never sure if I chose the right words, but it went pretty well (I think…?). We talked about how last semester in [Class B], a student had written on my semester evals that he found the conversation "unprofessional" (also, probably, because I was crying/tearful when I gave it – see [A previous faculty reflection log]!). I told my current students about that comment, and how it made me wonder what kind of profession, exactly, they want to be a part of." (11 Oct 2019).

This connection is extremely important for two reasons: 1) As Professor B explained to her class, she believed that it was important for her class to see her as a real person – something students sometimes place in the back of their minds; and 2) To remember that these conversations are, "an important step towards making us all more empathetic, compassionate, kind human beings - not words we typically associate with engineering." (26 April 2019) The way sociotechnical topics are discussed may have huge effects on the audience. Having a level of connection from social to technical by bringing in real emotions into the classroom is not only an effective way to reach students, but it shows a willingness to be open that may improve sociotechnical understanding and natural integration.

Simple Integration

In general, our team came away from the analysis process with a strong recommendation to, "keep it simple," for both faculty and students. If it's not kept simple, the professor is less likely to have the bandwidth to create effective integrations, they may not "fit" in the curriculum or the timeline of a busy semester, or the students might get lost in the ambiguous, abstract space outside of their familiar typical engineering classes. Professor B wrote:

> "Citing [Professor C] – less is more! [A different class taught by Professor B] is otherwise a traditional-ish class, with some active learning thrown in. It just has a major PBL [Project Based Learning] component now, and the project happens to require the integration of social considerations. [Class B] has the kitchen sink of every engineering education innovation that I consider exciting or a best practice. There is a lot going on in this class." (8 Nov 2019).

There is also the importance of planning ahead and, while attempting to keep to the schedule, being able to be flexible and move things as needed. Professor B continued: "I think that is something to do for the spring (assuming I teach [Class B] again) – make a plan, before the semester starts, for the specific interventions that I want to do, and incorporate them into the [pre-class daily assignments] and course schedule up front." (1 Feb 2019).

At the core of the observed solutions, sociotechnical integration is facilitated by a realistic perspective. Time is a limiting factor in the classroom, both during and in preparation, so looking for simple integrations to reduce time and effort are important to have effective integration.

Learning from Others and Sharing Knowledge

Like many things, effective sociotechnical integration is an iterative process. To find and refine effective sociotechnical teaching techniques, exchanging data and techniques is extremely helpful. This message was observed in the data from both Professor B and Professor A (respectively quoted):

> "I am not sure I really make evident for the students how to respond to the bullets above, or how to account for it in their engineering design. What I need is a really good example (ironic – given that I anticipate Jackie's paper for ASEE critiquing real world examples!) of how this has been done, or what has happened in the past when it hasn't been sufficiently accounted for." (8 Nov 2019).

> "I'm struggling with how to set-up these lectures…as I am writing this, I am going through [Professor D]'s [faculty reflection log] and learning a lot about what worked and what didn't work in the classroom. I am hoping that the students gain knowledge from this assignment but I am already predicting that there will be pushback from the students…I can't emphasize enough what great timing this interview assignment was with regards to reviewing [Professor D]'s [faculty reflection log] and also working on the ASEE paper focusing on the interview assignment. Although I am sure I can do better with preparing for the interview assignment, I think that students walked away with a clear understanding of the importance of 'getting out of the building'" (19 March 2019).

To summarize this theme, we have described some simple and effective concepts for sociotechnical integration. Specifically, (1) instead of putting a large amount of concentrated effort into a single module, spread out a few small assignments through the semester. (2) Since sociotechnical integration is what happens naturally in the real world, create assignments that are open ended and allow students to explore the solutions on their own. These assignments can be followed up with open discussions that facilitate sharing of ideas from multiple sources. (3) When using these open discussions or real-world examples, be considerate of ambiguity in these assignments. In comparison to the traditional closed-exact answer of technical problems, the social is often open-ended and that can lead to stress and a lack of receptivity.

At its core, education relies on the sharing of experiences and knowledge. This is also true when integrating sociotechnical thinking into the classroom. (4) When integrating sociotechnical thinking, this analysis suggests to go for simple integrations to ensure that both you have the energy to explain the concepts and the students to receive the concepts. (5) Share your experiences to help avoid pitfalls for future educators and to indicate what methods have worked well. (6) Lastly, consider adding the human element to your classes as real engineering problems rely on this human element just as much as it relies on the technical element.

Summary of Findings

In summary, the themes that emerged from our analysis, along with relevant domains, can be listed as follows in order from what we observed from the two classes studied and how these observations might support sociotechnical integration in other classes with suggested effective techniques:

1. The Relationship of Motivation, Engagement, and Receptivity to Sociotechnical Integration
    a. The Importance of Motivation: Engaging Students and Faculty
    b. Generating Motivation for Students and Faculty
    c. Student Engagement Leads to Receptivity
2. Successful Techniques for Sociotechnical Integration in Class
    a. Relatively Small Integrations Throughout the Semester
    b. Integrating with Real World Examples
    c. Difficulties of Ambiguity or Open Problems
    d. Creating an Emotional Connection
    e. Simple Integration
    f. Learning from Others and Sharing Knowledge

Discussion and Conclusions

This paper was derived from data in reflection logs written by two professors who are members of our research team, which means that all data may be colored by each professor's own biases. Involving three additional research team members in the analyses and using a collaborative inductive analysis process has helped to reduce the impacts of such biases and to make the findings more useful to a larger population of engineering educators.

At the center of this work are two key themes. The first is the relationship among motivation, engagement, and receptivity to sociotechnical integration. In the goal of sociotechnical integration, a main consideration will be the student retention of information and concepts. By promoting intrinsic motivation for students, engagement will follow, supporting motivation for professors, and finally student receptivity to ideas. Real world, open-ended concepts that allow for students to engage more deeply with subjects they find interesting can support such motivation and engagement.

The second theme that emerged from the data asks the question, "what are some effective techniques to use to improve sociotechnical integration?" Instead of having one large module or section of the class focused on sociotechnical, the faculty reflection log analysis suggests professors to include a few small integrations throughout the class. Even during technical discussions, it is easy to add questions such as, "Who benefits? Who suffers? Who is not 'at the table'?" that illuminate existing social elements for students to consider. This finding is consistent with prior work such as is described in [5]-[6]. Our data suggests that allowing students to explore sociotechnical concepts through a variety of methods in a class can encourage them to discover the importance of social considerations to even technically-heavy problems. However, it is important to be mindful of the difficulties of ambiguity in open ended problems. In comparison to the traditional closed single answer format, open ended problems, if not clearly stated as open ended, may cause dejection and stress in students, which is consistent with findings in the literature suggesting that students find these problems to be more difficult [22].

Continuing with the second theme, integrating sociotechnical thinking in the class may require some iteration and new styles of teaching, both of which can be supported by the sharing of ideas. During integration, look for simple solutions or techniques. Professors have limited bandwidth, time, and energy to devote to any single class. Share your experiences, hurdles, and successes with others, and when considering new ideas or techniques, look to others to see what has and has not worked well for them. Another strategy to consider is bringing your whole self to the classroom. If there is a social element to problem solving, why not shine a light on our own humanity? One goal is to create future problem solvers with more empathy and considerations to the human element inherent in engineering but often missing in the classroom.

Similarities and Differences in Faculty Reflection Logs

Similarities: Some similar insights shared between Professor A and Professor B with respect to faculty reflection logs included time constraints, faculty burnout, faculty imposter syndrome, and a disconnection with students. Some of these logs reflected a combination of two or more of these challenges which made it difficult for faculty members to include more sociotechnical integration content within their course curriculum. However, Professor A and Professor B also obtained valuable feedback on what anchors and techniques seemed to work well with students, such as the interview assignment and lab-on-a-chip, as well as what needed to be changed, such as expanding project dates so students have more time to work on them, to creating new anchors altogether (i.e. eInk to lab-on-a-chip).

Differences: Some key differences noted within both faculty reflection logs included integration teaching techniques and faculty support for sociotechnical integration. While Professor A had more open discussions and meetings with other faculty members on the inclusion of sociotechnical thinking into the course curriculum, Professor B did not have the same interaction with other faculty members because it was the only section of the course taught each semester. Although this was not a direct insight but rather an indirect one, it seemed to have added additional challenges to Professor B, which may contribute to faculty burnout and an increase in imposter syndrome. The other key difference in both faculty reflection logs included sociotechnical integration teaching techniques, where Professor A had a more project-based technique, while Professor B's teaching technique included more prompts/anchors to their technique. It should be noted that although both techniques were different, both seemed to have resonated on some level with students.

A substantial limitation of this paper is that it draws only from faculty-generated data. Future research will examine the intersection between this paper's faculty perspectives and student-derived data from other sources within the broader project (focus groups, assignment data), which will allow for additional triangulation that will increase the reliability of the results.

Our team has found sociotechnical integration to be hard but rewarding, a message that is repeated again and again in the faculty reflection log data. We encourage engineering educators to consider the ways in which such integration can benefit both them and their students and to seek manageable ways to enhance their practice. Because we have found reflection to be so important in our own practice, we conclude this paper with reflective thoughts from each of this paper's co-authors.

Researcher E: Although not the focus of this work, one thing I wish to touch on is the importance of the core concept of sociotechnical integration. One concept that has been discussed, both in this team and in my life is, "What is an engineer? (And how deep do you want to go for your definition?)" I suspect that if you asked 1000 people, you would not get the exact same answer twice. The content of this paper is important to me personally because I think it relates to one of the core engineering concepts which is, ~" Your solutions need to be able to work *for* the recipients, which may include people you had not considered initially." No matter how effective a solution is, if it is not adopted by the people it is built for, it's a bad solution. At its core, engineering requires a human element which can be unfortunately absent in a majority of engineering-technical classes. Sometimes fresh out of college engineers don't even understand that our job is not 100% math and formulas. Sometimes these fresh engineers can become disillusioned with engineering as a whole and leave it behind and I see that as an issue with engineering education that isn't impossible to fix. Thinking about who is affected and to what degree needs to be a consideration, even in classes that are heavy to the technological and math side, because it's one of the real elements of being an engineer.

Professor A: As a faculty member who wrote a faculty reflection log and also analyzed the faculty reflection logs, it became clearer that this technique of reading and analyzing other faculty's thoughts is a powerful tool for reflecting on one's own teaching and internal struggles with teaching new topics, especially sociotechnical integration. It was comforting knowing that other faculty were experiencing difficulties with sociotechnical integration into the classroom. From my own experiences and perspectives, lessons learned that would improve this experience moving forward include; 1) work with other faculty to implement difficult to teach topics in the curriculum, 2) continuous improvement and reflection is important because one rarely gets it right the first time and that is okay, 3) one must be motivated to do better and become a better teacher or instructor, 4) keep it simple and 5) make sure examples are relevant and exciting for students. Through this experience of writing and analyzing faculty reflection logs, I found that most other faculty struggle to implement new concepts into the classroom and sociotechnical integration is, in fact, hard to do. However, working as a team is a supportive and collaborative way to integrate sociotechnical thinking in the classroom.

Researcher F: As previously described, it is important to teach future problem solvers to include empathy and consideration in their solutions, rather than only focus on the technical aspect of a problem. There are many ways in which faculty can incorporate sociotechnical classroom examples, also known as anchors, into their curriculum. In my opinion, I think part of that sociotechnical learning comes from smaller and more frequent applications of these anchors in the classroom. Another aspect that I think is important to note is the frequency in which imposter syndrome appeared during the analysis of the faculty reflection logs. As a student analyzing these faculty reflection logs, I would have never thought that faculty also questioned their teachings and whether or not it worked well for students. Although this should not be shocking, it was eye-opening to realize how conditioned students have been to heavily focus on the technical side and how little we have been conditioned to focus on the non-technical side. In my opinion, having that rapport with professors, and seeing their "human" side, makes it easier for students to approach sociotechnical integration and more open to discuss anchors in class or in the future.

Professor C: The concept of sociotechnical thinking may be unfamiliar as a teaching topic to many U.S. engineering educators, but the process of integrating it can be highly rewarding to professors and students alike, and will ideally benefit the engineering profession and broader community as these students graduate and begin their professional careers. The act of reflection is a powerful means for improving teaching and should not be overlooked as part of the educator's toolbox. The reflections our team analyzed in this research illuminated the ways in which motivation, engagement, and receptivity intersect for both students and faculty and provided insight for other educators who share similar interests.

Professor B: As a researcher who wrote a faculty reflection log but was not a part of the analysis, it was very gratifying for me to learn about the findings that emerged from our faculty reflection log data. More than anything else, the process of writing these faculty reflection logs each semester underlined for me the value of reflection exercises for learners of all levels. I understand that there is a lot of engineering education research which demonstrates the benefits of reflection activities, and I have occasionally incorporated reflection activities for my students. However, I have not had the discipline to regularly self-reflect on my teaching until this research project. I appreciated the opportunity to engage in this practice, and am hopeful that my personal ramblings might benefit other faculty who are also headed down the simultaneously challenging and rewarding path of sociotechnical integration.

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