Engineering Identity, Perceptions of Sociotechnical Education, and Views of Engineering Practice in Undergraduate Students

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***Abstract*—Engineering education is widely perceived as focusing entirely on difficult technical analysis at the exclusion of consideration for the social contexts associated with such work. However, in reality, engineering practice is concerned with defining and solving problems which are both technical and social in nature and which require professional engineers to understand the complex connections between technical and social considerations. In recent years, there have been efforts across a number of research projects and curriculum development efforts to integrate sociotechnical thinking into students' engineering courses. This paper leverages one such project to explore the connection between sociotechnical thinking and the development of an engineering identity in students. It presents the results from analysis of student focus groups using inductive coding to explore the connections between students' beliefs about engineering practice, their perceptions of sociotechnical thinking in their engineering education, and their self-reported engineering identities. We identify and describe four clusters of students which capture the most common interactions between these three dimensions and discuss the implications of these clusters for broadening participation in engineering and engineering education.**

Keywords—engineering identity, engineering practice, sociotechnical thinking

I. Introduction

A growing number of engineering education researchers have called in recent years for increased integration of sociotechnical thinking into engineering courses and curricula [1]–[3]. Engineering practice has been shown to be inherently sociotechnical [4], requiring the integration of technical and social considerations to identify and address the problem or issue at hand. Researchers have also argued that sociotechnical education is a way to facilitate discussions around equity and social justice in engineering [5], [6] while also broadening views of who can be an engineer and the types of work engineers engage in [7], [8].

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However, there has been relatively little work exploring the complex interplay between engineering students' beliefs about engineering education and practice, their perceptions of sociotechnical thinking, and their self-reported engineering identities. In this paper, we aim to explore these connections by analyzing student focus groups recruited from engineering courses which included sociotechnical integration. The study described here emerged from a larger, mixed-methods NSF-funded project which explored the formation of sociotechnical thinking in engineering undergraduates [2]. This project spanned three different engineering core courses at two different universities. While the larger project did not originally aim to explore the interplay between sociotechnical thinking and the formation of engineering identity, the student focus group data gathered during the project showed unexpected connections between the two.

This paper sets out to explore such connections. Specifically, it presents results from thematic analysis of four student focus groups which aimed to answer the following research question:

> *How do engineering students' beliefs about engineering practice, their perceptions of sociotechnical thinking, and their self-reported engineering identities relate to one another?*

To answer this question, inductive coding was used to classify focus group participants' beliefs about engineering practice, their views of sociotechnical coursework, and their engineering identities. Using this coding, we were able to identify patterns in how their views on these three dimensions (engineering practice, sociotechnical thinking, and themselves) related or, at times, were in contrast with one another. We expect that this work will contribute to the growing body of research about how to most effectively incorporate sociotechnical thinking into the engineering curricula by illuminating how students with different views on engineering and on themselves might react differently to sociotechnical integration in their coursework. In turn, it also shows how sociotechnical integrations influence students' views of engineering practice and their own engineering identities.

II. Background

A. Sociotechnical Thinking and Learning

Sociotechnical engineering has been defined as, "the integration of the social and technical dimensions of engineering problems" [9]. It is often context-rich, ambiguous, and multi-dimensioned [7], and has been identified as an important aspect of engineering practice [4]. However, it is commonly deemphasized or explicitly left out of most engineering curricula. Researchers have hypothesized this is due to the common beliefs among engineering students and faculty that engineering is not concerned with public welfare [10], is depoliticized [11], and that social and technical concerns are inherently separate from one another within engineering systems [12]–[14].

In response to this need to better understand how sociotechnical thinking can be better integrated into engineering education, researchers have set out to measure and characterize aspects of sociotechnical learning. These efforts have included exploring how students conceive of sociotechnical engineering and how they respond to sociotechnical interventions in core engineering courses [2], [15]. Researchers have also pointed out the connections between sociotechnical approaches to engineering problem-solving and related constructs, such as social justice [5] and engagement with public welfare [16].

New course designs, classroom-based interventions, and curriculum revamps have also been developed to better integrate sociotechnical thinking and learning into engineering education. These include energy courses taught with a sociotechnical approach [3], [17], [18], a sustainable engineering course that emphasized sociotechnical systems [19], [20], and a set of engineering science and design courses redesigned to include sociotechnical thinking [2]. There have also been a number of curricular interventions proposed alongside or in addition to these new courses, including a proposal for an application such as drones being used as a center point for sociotechnical learning [21] and an assignment that encourages students to gather information on different approaches to a given engineering problem that can be easily adapted to multiple class contexts [22]. Finally, a few new curricula or degree programs have emerged with explicit and foundational reliance on teaching sociotechnical thinking, including the Integrated Engineering program at the University of San Diego [23] and the Humanitarian Engineering Program within the Engineering, Design and Society Department at the Colorado School of Mines [24].

Though such approaches to engineering education are increasing in number, research into how sociotechnical learning influences how students perceive themselves and their engineering work has been limited. Bilow et al. recently reported on preliminary work looking at how a sociotechnical-focused course impacted students' sense of belonging and their attitudes toward engineering [3]. Claussen et al. also used narrative analysis to explore connections between students' engineering identities and their views of sociotechnical integration [8]. With the growing interest in sociotechnical education, there is also an increasing need to more thoroughly understand how students react to and are impacted by such teaching.

B. Engineering Identity

There has been a variety of research written on engineering identity, including how students develop their identity [25], its importance in regards to retention and success [26], and the barriers that stop students from developing their engineering identity [16], [27]. Students develop an understanding of how they fit into engineering as a whole through their experiences. Put another way, "the formation of a student's engineering identity – their willingness to identify as an engineer and be identified as an engineer – is affected by how that student comes to understand what engineering is, a definition informed by their personal experiences and beliefs and what is presented in engineering courses" [8, p. 3]. Due to how students experience engineering, this can lead students to create justifications on whether they can identify as an engineer: "The factors that students most frequently identified as being necessary to be considered an engineer were intangible in nature and included: making competent design decisions, working with others to share ideas and accepting responsibility" [28, p. 1]. A dissatisfaction towards engineering as a whole could increase in students who find themselves unable to achieve the high standards they hold for engineers while at the same time unable to receive external validation from their peers, professors and/or organizations.

Students' views of engineering often also serve to underline its perceived exclusivity and difficulty. According to a longitudinal study exploring students' perceptions of engineering, "Participants' responses reflect a definition of engineering that may on the surface appear open but is in practice exclusionary to individuals who do not conform to certain expectations" [29, p. 1]. Students seem to create strict and narrow ideas about what it means to be an engineer, which in turn limits their views on the various ways in which one can become an engineer.

One way in which engineering educators might support these students is through developing curricula which makes visible and supports the other ways of approaching engineering problems. Rossmann et al. write, "Engineering students with historically marginalized identities who engaged with critical theorizing around identity, power and practice felt increased agency from the act of naming systems of power and oppression and, as a result, felt empowered to act in opposition to such systems. […] This form of empowered agency strengthened their identity formation and sense of belonging in engineering" [30, p. 13]. Giving students the tools to think about engineering not only critically, but also giving them the agency to think as an engineer in new and diverse ways may not only lead to stronger engineering identity in students, but a more diverse, responsible, and productive engineering profession as a whole.

C. Student Perceptions of Engineering Practice

Like the analysis described in this paper, much of the prior work on student perceptions of engineering has intersected with studies of their engineering identities [28], [31]. Researchers have drawn upon the perspectives of social scientists who study engineering alongside those of engineering faculty and students to answer the question, "What is engineering practice?" [32],

finding that engineering practice is composed of problem solving, engineering knowledge, and the combination of processes and knowledge. Critical scholars within engineering education have also explored questions around how engineering practice is perceived by engineering students [5], [20]. In many of the prior studies of engineering practice, the views and experiences of professional engineers or faculty are prioritized over the perspectives of students [4], [32], making it difficult to discern precisely how students view engineering.

A recent piece of work which is perhaps most similar to that of this paper aimed to classify students' views of engineering and engineers following completion of a sustainability-focused energy course taught with sociotechnical elements [7]. The research team found that students were beginning to alter their views of engineering to include a sociotechnical framing, but that it was only a partial or incomplete integration.

III. Methods

This work stems from a project exploring how to integrate sociotechnical thinking into core engineering courses and the impacts of doing so on students and faculty [2]. In the process, it also proposed frameworks and definitions for sociotechnical concepts [2], developed new methods of assessing and developing sociotechnical thinking in students [15], [22], and measured how students and faculty view sociotechnical thinking and learning [33], [34]. As part of that research study, our research team developed sociotechnical interventions in three engineering courses at two universities: an introduction to engineering projects and design at University A taken by first-year students across engineering majors (referred to as "Projects" in this paper); a sophomore-level introduction to mechanical engineering course at University B ("Intro to ME"), and a junior/senior-level engineering electromagnetism course at University B taken by electrical engineering students ("EM"). Details describing these interventions have been published elsewhere [2], [22], [35].

To assess the impacts of these interventions and gather information on students' views of sociotechnical thinking, we conducted eleven student focus groups distributed across the three courses, with a total of 49 students participating. During the focus groups, we asked questions about the students' engineering identities, their experiences in the course of interest and in prior courses, and their perceptions of engineering practice and the engineering curriculum. The focus groups were recorded and then later transcribed by an outside transcription service. The full focus group protocol can be found in [8].

After the focus groups were completed, two researchers were assigned to do an initial thematic analysis of each focus group transcript (two researchers were used to improve the trustworthiness of the analysis, as defined in [36]). Each researcher wrote an analytic research memo (ARM) identifying broad themes that emerged from the focus group. Then, the two researchers met to collaboratively write a single consensus analytic research memo (cARM) which captured the themes that they collectively observed and agreed upon. A similar analytical process has been employed and described in [37] and is based on methods proposed in [38].

Through this initial analysis, we observed persistent interplays between students' responses on three topics: their views of themselves (specifically with regards to their engineering identities), their perceptions of engineering practice, and their reactions to sociotechnical thinking. We have explored some of these relationships in [8] and [39]. In the work described in this paper, we build upon this early work to identify the most common patterns relating these three topics in a sample of four of the focus groups (total number of participants n = 17): one focus group randomly selected from both the Projects and Intro to ME courses and two randomly selected from the EM course (as this was the class where we had the highest number of intervention semesters and focus groups over the entire project).

A. Data Analysis

To answer the research question of this work, we split the four focus groups transcripts evenly between two members of the research team and began by reading them in depth. The objective in going through the transcripts was to obtain information on each student's viewpoints regarding their engineering identity as well as their perceptions of sociotechnical education and engineering practice. Once the two team members completed an initial review of their respective transcripts, they went back to the transcripts to find illustrative quotes. These quotes were organized into three categories which had become evident from the original cARMs associated with the focus groups: perceptions of sociotechnical thinking, their beliefs about engineering, and their engineering identities. We also wrote individual summaries about each participant based on their responses in these three categories.

Using the notable quotes and individual summaries, we then developed themes to characterize students' responses within each category, specifically seeking ways to group the students based on similarities in their responses. These themes are defined in Table I, below. We point out that the themes within the category *Views of Engineering Practice* are adopted from the one-dimensional sociotechnical continuum proposed in [2]. Another theme, within the *Engineering Self-Identity* category, "More experience required to identify as an engineer," was inspired by the work described in [8] and [39] on liminal engineering identities.

To group students based on their responses within the three categories and show relationships between the categories, we used the themes to create two tables: one that compared their views of engineering practice to their engineering self-identities (Table II) and a second one that compared their views of engineering practice to their perspectives on sociotechnical integration in engineering courses (Table III). (We would have preferred a table that combined all three dimensions into one, but felt that our findings were easier to comprehend if they were split into two separate tables.) We note that, in each of the three categories, we did have a theme termed, "Contradictory," as we found there were some students who were difficult to place due to them having contradicting viewpoints or not providing enough information with regards to the category at hand.

Each of the two researchers then separately placed the student participants into one theme within each of the three categories. To minimize potential bias and ensure the accuracy

TABLE I. DESCRIPTIONS OF EMERGENT THEMES

Category	Theme	Theme Description
Views of Engineering Practice	Technical-social dualism [2]	Sees engineering as requiring critical thinking and (technical) problem solving, and as completely separate from any social considerations or contexts. Believes engineering only involves building, designing, and solving mathematical problems. Emphasizes technical innovation (including making the user experience easier) and not on the broader social context. Their work and efforts are focused on improving the technical performance of the design, rather than doing so to help people, the community, or society.
	Partial integration of social and technical [2]	Sees engineering as combining technical and social considerations, but sees such integration as limited or incomplete, or places conditions upon it.
	Sociotechnical integration [2]	Views the engineering field as multi-faceted, and about more than just designing, building, and technical aspects. Understands how engineering can influence society and communities and considers this influence (sometimes even prioritizing it above all other considerations) when going through the process of creating. Has a holistic view of engineering, and account for the social context of their engineering work.
	Contradictory views of engineering practice	Has contradictory views on engineering practice.
Engineering Self-Identity	Does not identify as an engineer	Does not see themselves as an engineer and/or does not vocally identify as an engineer during the focus group.
	More experience required to identify as an engineer	Expresses that they do not yet identify as an engineer due to their (perceived) lack of experience with engineering [21].
	Identifies as an engineer	Sees oneself as an engineer and vocalizes this identity during the focus group.
	Contradictory or vague engineering self-identity	Has contradictory views on their engineering self-identity.
Perspectives on Sociotechnical Integration in Engineering Courses	Does not value sociotechnical integration	Sees sociotechnical integration is irrelevant or out-of-place in engineering courses.
	Values sociotechnical integration, but not as much as technical skills	Sees the value and importance of sociotechnical integration, but believes that technical skills, knowledge, and considerations still trump social ones in engineering courses and curricula.
	Values sociotechnical integration under certain contexts	Perceives sociotechnical integration as important or relevant, but only in limited contexts. These contexts could include as specific engineering or non-engineering courses; in certain applications, technologies, or engineering projects; or based on an engineer's specific role or task on a project.
	Values sociotechnical integration	Sees sociotechnical integration as integral and highly relevant to their engineering education and does not place limitations on such integration.
	Contradictory views of sociotechnical integration	Has contradictory views of sociotechnical integration in engineering courses.

of our findings [36], this was then repeated, with the researchers swapping focus groups and repeating the process of writing summaries, selecting illustrative quotes, and placing the participants in Tables II and III. In this way, two researchers reviewed and analyzed all four of the focus groups. Following the completion of their separate reviews, the two researchers then met to discuss their summaries of each participant and where they had placed the individuals in Tables II and III, and to resolve any disagreements. Through multiple discussions, they iterated toward the final versions of the two tables presented here.

IV. RESULTS AND DISCUSSION

In this section, we present the two tables created from sorting the focus group participants based on their responses in three categories: perceptions of sociotechnical thinking, their beliefs about engineering, and their engineering identities. Tables II and III present the findings from our data.

To provide more context on our most important findings, we identified the four clusters of students with the greatest number of students contained within them (each cluster contains four or more students within it). These four clusters are shaded in Tables II and III (two are found in each table). In the subsections that follow, we describe these four clusters, provide illustrative examples of the responses from students within each, and discuss the significance of each cluster. We also identify and describe outliers of interest, as we found the outliers occasionally gave us as much information as the larger clusters of participants. These outliers are indicated with an asterisk next to their name on the relevant table. The Appendix contains selected demographic information for each student, including their pseudonym, course, and gender.

A. Engineering identity and sociotechnical integration in engineering practice

The two clusters of students observed in Table II differed in both their engineering self-identities and their views of

TABLE II. COMPARISON OF STUDENTS' VIEWS OF ENGINEERING PRACTICE AND THEIR ENGINEERING IDENTITIES

Views of Eng. Practice	Engineering Self-Identity			
	Does not identify as an engineer	*More experience required to identify as an engineer*	*Identifies as an engineer*	*Contradictory or vague*
Technical-social dualism		Jay Tom	Link	
Partial integration of social and technical			Gerald Dan Bryan Seven *(Group 2)*	Colson Jane*
ST integration		Grace Kai Lilly Baphomet Roxy *(Group 1)*	Henrick* Ellie*	
Contradic-tory			Jack	

* Indicates an outlier discussed in the text of this paper.

TABLE III. COMPARISON OF STUDENTS' VIEWS OF ENGINEERING PRACTICE AND THEIR PERSPECTIVVES ON SOCIOTECHNICAL INTEGRATION

Views of Eng. Practice	Perspectives on Sociotechnical (ST) Integration in Engineering Courses				
	Does not value ST integration	*Values ST integration, but not as much as technical skills*	*Values ST integration under certain contexts*	*Values ST integration*	*Contradictory*
Technical-social dualism		Jay	Link Tom		
Partial integration of social and technical		Seven	Gerald Dan Grace Colson Jane *(Group 4)*		Bryan
ST integration				Kai Henrick Ellie Lilly Baphomet Roxy (*Group 3*)	
Contradic-tory					Jack

engineering practice. Students in the first cluster, referred to as Group 1, saw engineering practice as very sociotechnical, and at the same time, saw their own engineering identities as contingent on them gaining more engineering experience. Students in the second cluster, Group 2, had very secure and fully-formed engineering self-identities and perceived engineering as only a partial integration of social and technical considerations.

1) Group 1: Engineering as sociotechnical and engineering identities requiring more experience

As shown in Table II, we found that the majority of students who saw engineering practice as sociotechnical also believed they needed additional experience to identify as an engineer. There was, however, some variation in the degree to which the students linked their identities to acquiring more experience.

One notable student of this category was Grace who took the Intro to ME class. She expressed her motivation to pursue engineering in a way that included sociotechnical integration and also showcased the fragility in her engineering identity:

> I haven't really always known I wanted to be an engineer, I feel like I realized I wanted to do something that'd help the environment, like my junior year [of high school] and I came in like my senior year, like, 'I was like, hmmm, maybe I want to be an environmental engineer, cause I feel I want to do something like, I was like 'that's what's gonna help the world.' [...] That's what kind of made me start being [an] engineer, more just like being able to help the world in a sense. And I agree, I definitely don't view myself as an engineer yet, I feel like I obviously need more skills, but I guess my main motivation is finding a way to help others. I had science and math skills to do it, so this is what I want to do.

Grace demonstrates a belief shared among many of the students in Group 1: the notion that, despite holding strong sociotechnical motivations and views of engineering as a discipline, their core understanding of what it takes to self-identify as an engineer lies within the technical domain. To the students, a technical background is what makes an engineer, essentially disregarding any sense of engineering as sociotechnical, despite explicitly stating a sociotechnical view of engineering elsewhere. In essence, their views of engineering contradict their views of themselves. They see engineering as inherently sociotechnical, yet in order to identify personally as an engineer, they also believe they need more technical skills and experience.

As another example, in the Spring 2020 EM focus group, Roxy and Baphomet both expressed strong understandings of engineering as sociotechnical, but also had engineering identities based on gaining additional experience. During this focus group, two other students, Link and Tom, argued that there is a distinction within engineering, with some positions or project contexts that don't necessitate consideration of the potential societal impacts of engineering. Roxy pushed back:

> I kind of disagree with those statements because even though you're not the one designing the technology or whatever it is, you're still an educated official that is handling the technology so there's a potential of negative impacts you should be conscious of [...] and that should always be a thing that you have on your mind. You can't just wipe your hands because you're like, "Oh, I didn't actually design this."

Here, Roxy shows a quality that was observed among all of the students in Group 1. Even though elsewhere in the interview

Roxy indicated that she didn't have a strong engineering identity, she sees engineering as requiring sociotechnical integration at every level and in every job role. She was confident enough in this view to argue against Link and Tom who were both noted to have stronger identities than her. In this instance, Roxy demonstrates that through strong sociotechnical ideation, she is able to form opinions surrounding engineering practice and think critically about said practice.

For Group 1, we found that the main factor that was limiting the confidence these students have in regards to their engineering identity was the pressure they experienced (imposed by themselves or others) to have a strong technical background with very little space for sociotechnical integration. However, we hypothesize that sociotechnical coursework and curricula (such as the intervention courses studied as part of this larger project) might offer opportunities for these sociotechnically-inclined students to strengthen their engineering identities by broadening the messages they receive about what "counts" as engineering.

a) Notable outlier to Group 1

One notable outlier to Group 1 was Jane who was placed into the Contradictory category. The reason why she was placed there is due to the fact that when asked if she identified as an engineer, she herself stated that she would not until she gained more experience. Instead, she referred to herself and her peers as students: "I think as students, we've been given a lot of the tools and we've been taught how to develop those skills that engineers possess but I just don't think that we have the experience and hands-on stuff required to really consider ourselves engineers yet."

However, when talking about the importance of sociotechnical engineering in both classes and the professional sphere, she started to refer to herself as an engineer:

> ...When we think about technology, we think like, oh, who can this benefit and how is this helping people… I think as engineers, that's something we might not often think about because we think we're making technology for positive impact and to better society, but in reality there are a lot of times where technology can end up hurting people and I think it's important to consider that just in any context of engineering.

Jane's change of wording was noteworthy. She appeared to lack the confidence needed in order to present herself as an engineer when asked explicitly about her identity. However, when prompted to consider sociotechnical thinking, her engineering identity seemed to change. In Jane, it seems like the hyper-focus within engineering on technical skills may have contributed to her lacking confidence in herself and her abilities; similarly, prompts about sociotechnical thinking may have empowered her to take on this identity when she otherwise may have hesitated.

2) Group 2: Engineering as the partial integration of social and technical and strong engineering identities

The other large clustering of students in Table II believed in a partial integration of social and technical considerations within engineering practice and vocalized confident engineering identities. Seven, a student from the Intro to ME course, is one example of a student who showed interesting insight when asked about his engineering identity:

> I think [an engineering identity] really depends on what you're looking at here in a professional academic sense. You become an engineer the day you get your diploma, it's as simple as that. But as far as, you know, when do you exhibit the traits of an engineer? Well that's very subjective, very hard to pinpoint. Do you have to be book smart, is it the way you think? You can pick your criteria on that. But I think you'd get a different answer for everybody, and everybody will have a different answer for everybody else.

Seven is noted to have one of the strongest engineering identities within the entirety of the focus groups. He also saw engineering as only the partial integration of social and technical approaches. However, though Seven places technical skills as more important than sociotechnical ones, he does acknowledge that being an engineer can involve more than just raw technical abilities. He does this by recognizing that there are different facets to engineers that are applicable to different people and situations.

This observation can also be made when looking at the responses of other students in Group 2, such as Gerald. Gerald identifies as an engineer but does not identify with what he views as a "traditional engineer," which he defines as someone who applies existing solutions to problems that only slightly vary from one another. Gerald sees himself as possessing an engineering identity due to his passions and understanding of the engineering world outside the technical:

> Yeah. I would say I do identify as an engineer. However, certainly not majority identify as an engineer. I think the engineering processes is more what I identify with, being able to execute on a set of criteria but not necessarily... I don't know if I want to ever be a traditional engineer. So in that way I don't identify as it.

It is possible that the increased confidence the Group 2 students have in their engineering identities is related to their view that engineering requires only a partial sociotechnical integration. As a result, these students may be able to find more motivation within their technical-focused academic studies and do not find themselves limiting their definitions of who they are as engineers because they feel like their abilities align with their views that engineering is a dualistic, partial combination of the social and technical. By contrast, Group 1 places high value on sociotechnical integration, which seems to serve to possibly weaken their identities due to the messages they receive about engineering requiring technical experience and expertise. For students in Group 2, it seems that the increased levels of assurance they feel in their engineering identities correlates with the value they place in the technical side of engineering (and their sense that they are adept at this aspect of engineering), despite their acknowledgement that engineering contains some degree of integration of social considerations into that technical work.

a) Notable outliers to Group 2

We observed two notable outliers to Group 2. These outliers were students that both saw engineering practice as requiring

sociotechnical integration and who had strong engineering identities. One thing to note for this particular cluster of outliers is that both students were in the Projects class. Across the four focus groups analyzed for this paper, more students from the Projects class saw engineering as inherently sociotechnical than from any other class.

When asked about what influences their engineering identity, one of these outliers, Ellie, replied with how being considerate plays a major part to her own identity:

> The value I think about the most is to be considerate and just think of – when building something or when thinking of solving a problem – thinking of other people it will affect and how it will affect them, whether that's a positive or negative way and try to avoid because you can't just 100% completely avoid [affecting] someone or something in a negative way. […] To minimize that, […] that's something I feel I have to, or us as engineers have to think about all the time. At least, in my opinion, engineers want to better and not make things worse. Therefore, I think that's something I, at least, should think about a lot.

Ellie has both a strong engineering identity and greatly values sociotechnical thinking. She views engineering as more than just technical and sees facets of the engineering profession which she strongly supports and believes in. Similarly, the other student in this cluster, Henrick, echoes a very similar take on the profession when he spoke in length about the growing diversity within engineering and its connection to his own engineering identity:

> Well, I would say yeah [I identify as an engineer]. Not with the common stereotypes of engineers, how we're all just nerds and we just stay inside and build projects all the time, but I feel like the engineering population [has] grown so much and become so much more diverse that really, anyone can identify with [being] an engineer and say, enjoy building stuff and enjoy making the word a better place and have that as their main goal in their mind. I would say, [I] identify with that group of engineers.

Much like Ellie, Henrick has a strong engineering identity that is tightly intertwined with his own views on sociotechnical thinking. Both of these outliers are able to relate to what they perceive to be the sociotechnical side of engineering, and thus feel confident identifying as an engineer. The ability to see engineering as sociotechnical allows students who value sociotechnical thinking in themselves or others to, in turn, strengthen their own engineering identities. They do not limit themselves to what type of engineer they can be, but rather focus on what kind of engineer they want to become. By allowing themselves to do so, they are able to gain confidence in themselves as engineers.

B. Sociotechnical integration in engineering courses and engineering practice

Two clusters of students were observed in Table III, which compares their views of engineering practice with their perspectives on sociotechnical integration in the engineering curriculum. One of these clusters, Group 3, contains students who saw engineering practice as inherently sociotechnical and who saw the value of integrating sociotechnical thinking into engineering curricula. The second cluster, Group 4, contained students who saw engineering as requiring the partial integration of social and technical considerations, and saw sociotechnical thinking as an important but not integral part of the engineering curriculum.

1) Group 3: Perceives engineering to be sociotechnical and values sociotechnical integration in engineering courses

When prompted for his opinion on the appropriateness of sociotechnical integration in engineering education, Henrick reported that such integration is something that is expected of working engineers, and hence is highly relevant to teach to engineering students:

> Isn't that something that we're always going to need in industries? It's always going to be a part of us working as engineers, so why shouldn't we be learning it in a technical environment? We're going to be practicing it in a technical environment. I think it's very applicable.

In Group 3, this view of sociotechnical integration in engineering education was shared widely among the other students in this cluster. To them, learning to become an engineer and being an engineer both contain a great deal of sociotechnical integration in all aspects. What was interesting to note, however, was that within Group 3, some of the students were the same ones who reported not having strong engineering identities in Group 1, citing their lack of technical experience as their reason for not fully identifying as engineers. Even though they cite a desire for more technical experience, we also see that they express the need for strong sociotechnical capabilities to be taught in engineering education. They see this skill as vital within the professional field, as exemplified by Baphomet, a student in the EM course:

> As technologies are introduced into the world, there are several stages at which someone could potentially intervene or have an effect on how far it goes, the checkpoints essentially. I think that it gets kind of dangerous when people adopt the mindset that, well, it's just not my job to care what this technology is for. If you're an engineer and you're working with these things, it's important to always have that awareness.

This cluster of students expects engineers to fulfill certain responsibilities. They see engineering as sociotechnical; these students expect engineers to solve problems so that the solutions account for elements beyond the technical sphere, including attention to who could be impacted by the solution.

2) Group 4: Sees engineering as the partial integration of social and technical and places conditions on sociotechnical integration in their courses

In our final group, we observe a cluster of students who see engineering as the partial integration of social and technical considerations, and believe that this integration only has a place in the engineering curriculum in certain contexts. To the students in this Group 4, sociotechnical integration in their education is only valuable and necessary at specific times and places.

When asked about their views of sociotechnical integration in engineering education, Dan, an EM student, said that he

thought there is not enough time for students to be fully taught both technical and sociotechnical content within their class:

> I think, if all of our classes where we're learning these technical things, if we took time to think about the sociotechnical stuff in all of them, we, I don't know, I feel like we'd run out of time to learn everything. I feel like there's a time and a place to think about this stuff, and it's probably…Definitely for practicing engineers, when you're brainstorming ideas and stuff, you should be thinking about who it affects, but when we're just learning about how waves move and stuff like that, I don't think that's necessarily the time to be learning about that.

Dan's words here exemplify the contradictory views held by the students across Group 4: that while engineering practice has elements of being sociotechnical, there is a time and place for learning it in engineering courses. This group, in particular, conveys a sense that technical-heavy content is the more valued and important part of what is taught in engineering courses. At the same time, they are able to see the importance of sociotechnical work and why it is vital for a professional engineer to have skills beyond just technical ones. Despite this group placing a heavy focus on the technical side of engineering, they also acknowledge the relevance of sociotechnical thinking.

V. Summary of Discussion

Our analysis demonstrates that there are many students who are like those in Group 1: they see engineering as sociotechnical, yet struggle to identify as engineers because their education and coursework does not value or emphasize sociotechnical thinking. Thus, including more sociotechnical thinking into engineering courses could help these students identify more fully as engineers. When students are given the space to picture themselves as engineers, it allows for them to identify with the field of engineering.

There was also a very high number of students who mentioned the importance of sociotechnical engineering (seeing engineering as a complete or partial integration of sociotechnical considerations). All four of the major clusters described in this paper contained students who reported some semblance of sociotechnical values. If students are able to see the importance of sociotechnical integration in engineering, why is there not more integration within the engineering courses? The expectation that every student will excel in engineering by being presented only with technical-focused content risks marginalizing the students who see engineering or their own engineering identities as sociotechnical; it also presents an inaccurate picture of what engineering practice is actually like [4].

When the focus of engineering education becomes too technical-heavy, the degree to which these students are willing to identify as engineers decreases and, in some cases, appears to lead to disillusionment as their views of engineering as sociotechnical come into conflict with the other messages they receive from their peers, faculty, etc. about what it means to be an engineer. However, when students are given space to see engineering in a much broader sense, some students may be more willing to take on engineering identities, like Jane did. This could in turn allow them to find much more meaning within this field of study and allow higher retention in engineering programs.

The clusters we saw in Groups 3 and 4 were not particularly surprising. It made sense that there would be a large group of students who saw sociotechnical integration as integral to engineering, and thus thought it should be a prominent part of their engineering education (Group 3). It also seemed rather expected that many of the students who saw engineering as only the partial integration of social and technical work would place limitations on when and the degree to which sociotechnical thinking was taught in their engineering education (Group 4). However, even these students with fully developed engineering identities and who emphasized technical practice within engineering could see the importance of (partial) sociotechnical integration in that practice. Even though some believed sociotechnical thinking should only be taught in certain contexts (as seen in Group 4), these students still valued sociotechnical integration.

VI. Conclusion

This work identified the most frequent connections made by engineering students in focus groups between how they experienced sociotechnical integration in their undergraduate coursework, their engineering identities, and their perceptions of the engineering profession. It follows from previous work which showed initial connections between students' engineering identities and views sociotechnical learning, but which fell short of systematically characterizing such connections [8]. It also builds on other analysis which used quantitative data to look at students' gender identities and how they relate to views of sociotechnical engineering [40]. Together with these previous publications, the work described in this paper makes evident that students' views of sociotechnical are influenced by their engineering identities, personal identities (such as gender), and perspectives of engineering practice.

Awareness of these connections is important for faculty members aiming to incorporate sociotechnical thinking into their courses. Our findings show that successfully bringing sociotechnical thinking into the classroom may require instructors to also engage with students' identities and views of the profession to ensure their buy-in and convince them of its relevance to their future practice. This differentiates the integration of sociotechnical thinking from other, more familiar content that engineering instructors might bringing into their classes – like a new simulation tool or a novel technical concept – which may already align with their views of engineering and dominant engineering identities. Failure to acknowledge the connections between sociotechnical thinking and students' identities and views of engineering may reduce the likelihood of success of sociotechnical course-based interventions, especially among certain clusters of students with strongly-held engineering identities.

At the same time, we propose that further integrating sociotechnical thinking into engineering classes could support some students who do not strongly identify with the dominant views of engineering, especially those who value engineering as a sociotechnical undertaking. Introducing sociotechnical

concepts may contribute to a greater sense of belonging and higher motivation among some students through contextualizing the topics they are learning. In our focus groups, it was evident that when the students felt that their engineering identities were limited due to the believe that technical skills and abilities were valued above any sociotechnical ones, this sense served to undermine the other qualities they possessed and which they professed to value highly in professional engineers. It is our claim that increased sociotechnical integration may lead to more students finding aspects of engineering to identify with – essentially broadening the definition of what it means to be an engineer – while also bringing engineering education into closer alignment with the realities of engineering practice.

In future work, we hope to expand our research to focus on the views of marginalized engineering students of sociotechnical integration and their perspectives of engineering practice. (The original study set out to do this, but due to a very limited sample of students from nondominant groups, no conclusions could be drawn.) We believe that, armed with additional information on a broader group of students, we might gain more insight on the formation of engineering identities within undergraduate students and the connections between those identities and sociotechnical practice and learning.

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APPENDIX

DEMOGRAPHIC INFORMATION OF PARTICIPANTS

Pseudonym	***Focus Group***	***Gender Identity***
Baphomet	*EM, 2020 Spring*	*Female*
Bryan	*EM, 2019 Fall*	*Male*
Colson	*Intro to ME, 2019 Spring*	*Male*
Dan	*EM, 2019 Fall*	*Male*
Ellie	*Projects, 2018 Fall*	*Female*
Gerald	*EM, 2019 Fall*	*Male*
Grace	*Intro to ME, 2019 Spring*	*Female*
Henrick	*Projects, 2018 Fall*	*Male*
Jack	*Projects, 2018 Fall*	*Male*
Jane	*EM, 2020 Spring*	*Female*
Jay	*EM, 2019 Fall*	*Male*
Kai	*Intro to ME, 2019 Spring*	*Female*
Lilly	*Projects, 2018 Fall*	*Female*
Link	*EM, 2020 Spring*	*Male*
Roxy	*EM, 2020 Spring*	*Female*
Seven	*Intro to ME, 2019 Spring*	*Male*
Tom	*EM, 2020 Spring*	*Male*