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Exploring the Nexus Between Student's Perceptions of Sociotechnical Thinking and Construction of their Engineering Identities

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Practice (Wiley-IEEE Press, 2018). His current research grant project explores how to foster and assess sociotechnical thinking in engineering science and design courses.

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Introduction

In the United States, engineering education traditionally prioritizes learning the technical details of math and applied science over understanding the complex social, political, and cultural landscapes which shape and direct the problems and solutions generated by engineers. It is well documented that the practice of engineering requires heterogeneous interactions involving both people and things - humans and technologies - yet often the focus of schooling remains on the inanimate equipment rather than the messy people [1]–[3]. Moreover, engineering courses which include a focus on human interactions like communication and teamwork are undercut by the inaccurate and demeaning labeling of these as "soft" rather than "hard" skills to learn.

This false divide between hard and soft, between the technical and social, is increasingly outdated and ineffective in preparing engineers to understand and address the complex sociotechnical problems of the modern world. Engineering students initially attracted to the field by social good messaging like "engineers make a world of difference" can feel duped when the majority of their coursework is narrowly focused on understanding technical skills and theories devoid of social context [4]–[7]. 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. Bridging the sociotechnical divide (also referred to here and in prior work as technical/social dualism) through meaningful integration of social and technical issues simultaneously in engineering coursework is one means of illuminating the range of what constitutes engineering [8], [9]. It also expands the scope of acceptable engineering identities to include those who care not only about technological innovations but also about social impact and cultural change.

This paper presents results from a study exploring the connections between students' perceptions of sociotechnical thinking and engineering identity. The study is part of a larger NSF-funded project exploring the formation of sociotechnical thinking in core undergraduate engineering courses across two universities and three different courses, each taught by a different instructor. In our broader project, we have collected data from multiple sources, including student work, faculty reflection logs, pre-/post-surveys, and student focus groups. Our project did not originally intend to explore connections to engineering identity formation in students or professional practice. However, while analyzing the student focus group data, we observed that engineering identity was impacting students' responses in unexpected ways. Thus, this paper aims to answer the following research question:

> *How are students' conceptions of engineering identity linked to their perceptions of sociotechnical thinking?*

Background

Sociotechnical integration in engineering education

Multiple studies of engineering practice have underlined the necessity of integrating social and technical considerations in engineering work [3], [10], [11]. Yet, such sociotechnical integration has historically been difficult to achieve in the engineering curriculum. This is due, in part, to the structure of many engineering curricula which often emphasize technical engineering science courses and rely almost exclusively on closed-ended, decontextualized problems [12], [13]. Neeley et al. [14] describe the historical progression of such integration in their review paper, in which they observed four surges in activity around applied science and technology studies. They describe the most recent of these, in 2017-2018, as "embedded sociotechnical systems thinking" (p. 11), a time period which also saw the beginning of the research activities described in this paper.

Design courses, which can provide many opportunities for sociotechnical integration, are deprioritized in most engineering programs, as are courses in the humanities and social sciences [15], [16]. Through choices in curriculum and content, we see that engineering education often reinforces the false divide between the social and technical in engineering [17]. Though uncommon, sociotechnical integration has been attempted within the context of specific courses. These include Andrade and Tomblin's inclusion of social context in the course Engineering for Sustainability [18], [19], sociotechnical engineering taught in an introductory course [20], a team-taught, community-engaged engineering projects course [21], and a controls system course with integrated social justice components [22].

A lack of sociotechnical integration in engineering courses has been hypothesized to be associated with engineering students' decreased interest in public welfare over the course of their studies [6], [8] and the lack of attention to social justice in engineering education and practice [13]. Without sociotechnical integration, educators also risk inaccurately conveying to students that engineering involves solely decontextualized problems, when in fact all engineering work resides in a social context [23].

Engineering identity

Engineering identity – how it is defined, how it is developed, and how it impacts students – has received increased attention in engineering education research over the last few years. For brevity, we focus in this background section on a few key and recent papers or studies that are representative of the extensive work in this area.

Tonso's 2014 chapter on engineering identity in the *Cambridge Handbook of Engineering Education* divides conceptualizations of engineering identity into three categories: general social science constructions of identity; collective engineering identity; and engineering identity through a developmental psychology lens [24]. Tonso outlines the importance of identity to learning, explaining that learning is "a change in identity that comes with participation" [24, p. 267]. She underscores that learning involves much more than the accumulation of disciplinary knowledge, and that research is needed on "how reforms in engineering are taken up in identity productions" [24, p. 278]. The work described in this current paper focuses on this intersection between a change in pedagogy and students' engineering identities.

Recent research proposes both quantitative and qualitative ways to measure engineering identity. For example, Godwin developed a survey to measure engineering identity, with a focus on three constructs: recognition as an engineer, interest in engineering, and performance/competence in engineering [25]. Meyers et al. also used a survey to model engineering identity development employing stage theory [26]. They found that male students, students further in their studies, and students with future career plans in engineering are more likely to self-identify as engineers.

Extensive work in engineering studies underlines the connection between students' perceptions of "real" engineering work, their views of social responsibility and public welfare, and their own individual engineering identities [13], [27]. Situated in this prior work, Niles et al. used interviews and ethnographic methods to study two engineering programs focused on public engagement [6]. They found that,

> Students expressed that they had to defend engagement with public welfare as a legitimate aspect of "real engineering" and their identities as legitimate engineers. For these students, establishing an identity as an engineer involved navigating a dualism that frames engineers as highly technical people and that deems anything outside of the "technical" to be either of lesser value or outside the scope of engineering. [6, p. 497]

Students who were interested in public welfare often rejected or distanced themselves from engineering identities, a repositioning that enabled them to be true to their own values but inadvertently left "the technocentric emphasis of engineering identity intact. Since what it means to be an engineer plays a large role in delineating engineering ethics and practice (Downey et al., 2007), this represents a barrier for the adoption of broader engagement with public welfare in engineering as a whole" [6, p. 497].

A 2008 ethnographic study by Stevens et al. focused on "becoming an engineer" found similar connections between a student's identification as an engineer and their "commitment to meeting the challenges of rapid and unmarked shifts in what counts as engineering knowledge" [28, p. 365]. The authors argue that identification as an engineer may act like a compass that guides a student as they chart a path through engineering, a process that is made easier if the student can envision their future self as an engineer.

Finally, a recent systematic literature review by Morelock explores how engineering identity has been defined in the research literature, factors that impact engineering identity development, interventions that have been developed to encourage engineering identity development, and ways to measure engineering identity [29]. Due to the complexity of identity, Morelock calls for additional descriptive qualitative research on engineering identity, as these methods might be better suited to exploring its diverse aspects than "simple binary observation via tangible markers" [29, p. 29].

Liminal identity

Studying engineering identity formation during a student's undergraduate education means that we are simultaneously investigating how individuals transition from a student identity to a professional identity. This transitional, or *liminal*, identity formation process is also temporal, meaning it is clearly bounded in time and is, by its very nature, impermanent – no one expects to be a student forever. The status of student has a clear origin point as established by the admissions process, and a clear departure point as celebrated by the "grand opera of graduation" [30, p. 4]. Between those two points in time, student engineering identities are being shaped and molded. Bookended by experiences prior to becoming a student and by expectations of a future professional engineering career, the actual college experience exists in the liminal space in-between. Although liminal spaces are often described as *psychological* spaces between two identities, they can also encompass *geographical* and other spaces. For instance, a student may not be at home with family but not yet in a career that can take one away from one's hometown and college town. Of course, psychological, geographical, and other spaces interact, since students away from home exist in an in-between space to try on new and evolving identities. Such liminal spaces allow a window into one's future (imagined) self as well as a window into the kinds of messages one is internalizing about the future from the present context [31].

The expectations, beliefs, and dreams about what a future as an engineer looks like and consists of are powerful in establishing an imagined "future self" or a future professional identity as an engineer. Student engineering identities are constantly being (re)formed to align with the desired "future self" one envisions for oneself. In other words, "Learner identities will be expressed through, and also shaped by, different ways of seeing the future self" [30, p. 5]. Learner or student identities in the present can be challenged by threats to an imagined future, and an imagined future self can also serve as a motivational resource, as a goal to keep striving towards [32].

While the concept of liminal identity has been explored in conjunction with examining identity development in K-12, higher education and adults [31], discussions of liminal identity are rare within the engineering education literature [33]. As such, this paper marks a foray into investigating the connection between liminal identity development and engineering identity development. We use liminal identity as an organizing concept and analytical tool to highlight how the identities of engineering students are in transition, informed by their perceptions of future selves but expressed through their present conditions.

Research Methods

In this paper, we describe findings from focus groups conducted over four semesters within engineering programs at two public universities in the U.S. Rocky Mountain region. Over the course of the project, a total of eleven focus groups were conducted for three courses: a first-year introduction to engineering projects class at University B, a second-year introduction to mechanical engineering (ME) class at University A, and a third-year electrical engineering (EE) engineering science core course at University A. In all except one case, the courses were taught by one of the members of our research team (these instructors are also all co-authors on this paper) and included some elements of sociotechnical thinking integrated into the course. In the one exception (Fall 2019, First Year course at University B), the research team member/co-author gave two guest lectures on sociotechnical thinking in the course. The courses span three years of a typical engineering curriculum and represent both introductory/project-based courses and a core engineering science course to facilitate understanding across a breadth of student experiences.

To protect students, the semi-structured focus groups were conducted by two of this paper's co-authors not teaching the specific classes from which participants were recruited. A second member of the research team, either a student researcher or faculty member, observed each focus group. Focus groups were recorded and later transcribed for analysis, with the transcriptions checked and edited to remove any identifying information prior to the analysis. The semi-structured focus group questions can be found in the Appendix. Additional information about the focus groups and initial analysis of the data are available in [34]. All aspects of the data collection and analysis were approved through our universities' human subjects research approval process.

To answer the research question posed in our Introduction, five members of our research team each selected and re-read in depth one of the focus group transcripts collected between Fall 2018 and Spring 2020 to try to understand the intersections between sociotechnical thinking and engineering identity. Specific focus groups were selected to represent a cross-section of our three classes, two universities, and four semesters. After considering the focus group as a whole, each co-author independently wrote a case summary focusing on a single participant in their assigned focus group from whom we believed particular insight could be drawn. Information about each focus group is provided in Table 1, along with the pseudonym of the selected participant from

Table 1: Student focus group participants from whom data was drawn for this paper. This table also includes the name of the author from this paper who wrote the case description for each student.

Student Pseudonym	**Course**	**FG Semester**	**Student Demographic Data (if known)**	**Case Summary Author**
Becca	First-year engineering projects course, University B	Fall 2018	Female, probable first-year, other data not collected	K. Johnson
Dorothy	First-year engineering projects course, University B	Fall 2019	Female, first-year, other data not collected	J. Blacklock
Cleopatra	Second-year introduction to mechanical engineering course, University A	Spring 2019	Female, self-described sophomore, probable ME major, other data not collected	S. Claussen
Jay	Third-year EE engineering science course, University A	Fall 2019	Male, junior, other data not collected	J. Leydens
Link	Third-year EE engineering science course, University A	Spring 2020	Male, senior, white, EE major, not a transfer or international student	J. Tsai

each focus group and the known demographic data about that participant. After the initial drafts of the five case summaries were completed, each summary was carefully read and edited by a second co-author who had also read that particular focus group transcript. This step served as a validation step to minimize any potential bias. Following the finalization of the case summaries, we began to meet regularly to discuss our impressions and develop the findings for this paper following a case study methodology approach [35]. For this case study, we are aiming to better understand the specific cases at our two universities and their impacts on individual students by delving deep into these five students' statements during the focus groups. This process aligns with an instrumental collective case study approach [36] since we have three cases (the three courses of interest) and seek to answer particular research questions. The case summaries were written using thematic narrative analysis [37].

Findings

We present below the case summaries of individual student participants from the five focus groups listed in Table 1. Each summary begins with a description of the focus group, including the dynamics of how the participants interacted and what stood out from that particular focus group. The remainder of each case summary focuses on the responses of a single participant and describes the relationship between that student's self-described engineering identity and their perspective on sociotechnical engineering.

Case: Becca

In this focus group, all participants were women enrolled in the first-year engineering projects course ("Projects") at University B. They were animated and comfortable both agreeing and disagreeing with each other, so much so that the focus group facilitators ran out of time before being able to finish the semi-structured focus group question list because of the length of their responses and discussion among participants. During the debrief at the end of the focus group, the co-facilitator pointed out that the group seemed especially outwardly focused "on world applications and potential harms or improvements to society" (00:00:24 of debrief). Multiple participants in the focus group were good candidates for this case. In the end, Becca was selected because her views often contrasted with stereotypes for engineering. This case summary provides sample statements illuminating Becca's conceptions of sociotechnical thinking and engineering identity in three categories: her self-identification (or lack thereof) as an engineer, the importance she sees in people with different skillsets working together, and her views of how engineering impacts people.

Identification (or not) as an engineer

Becca immediately identified as an engineer when asked, "Do you identify as an engineer, and why or why not?", but then reversed and qualified her answer. Becca's answer here suggests that her engineering identity may occupy a liminal space, as she both identifies and does not identify as an engineer:

> I would identify as an engineer. Partially because of how I look at situations and how I think about things, but it's also kind of where I don't identify as an engineer… Well, the

> stereotypical engineer is very logical, math and science oriented but I really enjoy a lot of creative writing or reading and just anything that will take me to a different world or universe instead of just staying in this one. And that doesn't normally fit with engineering. (00:22:23)

Her first answer was to identify as an engineer, but then she described engineers by common stereotypes ("very logical, math and science oriented") and how her interests ("creative writing or reading") extend beyond that stereotype. Such a stereotype is particularly intriguing in light of calls for engineering education to integrate more opportunities to learn innovation skills (Byers et al., 2013; Ferguson et al., 2012; National Academy of Engineering, 2004), which depend on imagination. Becca's responses to the question, "What values or attitudes do you hold…that influence your identity or lack of identity as an engineer?" included imagination, which she explicitly connected with her engineering identity. Describing a castle she and a friend built using engineering principles, she told us, "That's really where I first saw imagination really tie into engineering, and then from there I've been able to see imagination in other parts of engineering. It's been a lot easier to identify it since then" (00:26:51).

Importance of people with different skillsets working together

Becca gave several responses that suggest her engineering identity includes being an imaginative and creative collaborator. Describing her group's work, she told us, "So, especially when we're brainstorming, I'll come up with an idea and be like 'Can we possibly achieve this'? And then they'll think on it more and be like, 'Yeah, okay. I think if we use a force sensor and some other things we can do this, we can make it happen' and then we go from there" (00:14:11).

Finally, in response to the question, "So how did your Projects [first-year engineering course] instructor convey the concept of socio-technical engineering?", Becca highlighted a website used in the class that illuminated ways that engineers might seek opinions from others on ethical issues tied to self-driving cars, and where people could also get a sense of how their ethical decisions compare to those made by others.

> There's a website that we were looking at and it's basically this quiz and it gives you two scenarios, and like which scenario would you choose? So it can give you, in a situation where somebody has to get hurt, there's no way around it, would you choose to kill five dogs or one person? Or would you choose to kill three executives vs. three homeless people? It's a lot of questions like that and they created that website to just get everybody's opinion, not just the opinion of the people working on the self-driving car. It was really eye-opening to look at... (00:41:47)

Engineering impacting people

Becca's responses to several other questions demonstrated that she is aware of ways that engineering impacts people. The impacts she described during the focus group are unidirectional: engineering impacting people, not people impacting engineering. This contrasts with a more complex bidirectional emphasis in science and technology studies in which society also influences technology (e.g. [10]). Commenting on what sociotechnical elements she learned in the class, she said, "I think for me it's more about how engineering affects people. Previously what I had learned in engineering was how to do things. How to use these tools to make a civil engineering floor plan, or how to make all these different things in CAD. Now we're learning about…how it impacts other people" (00:34:56). Becca's response here aligns with the work of Faulkner, which has identified that engineering is both technical ("technicist," as Faulkner terms it) and social ("heterogeneous," in her terms) [9]. She has also pointed out that how one navigates this duality depends, in part, on other identities that person may possess, including their gender, which may be at work in Becca [41].

In summary, Becca described an engineering identity that seems highly compatible with sociotechnical thinking, including a willingness to challenge perceived engineering stereotypes. Her engineering identity does not appear to be strongly tied to her year in school or employment as an engineer, but rather to inherent skills and interests. This is in contrast with other focus group participants in different classes/years, a trend demonstrated in the case of Cleopatra below.

Case: Dorothy

The next case analysis was created from a focus group that included four students from the first-year engineering projects course, including a student named Dorothy. This group presented dynamic responses to the focus group questions with many tangential conversations around ethics and women in engineering. Dorothy was selected for this analysis due to her consistent reflections on engineering practices in academia and industry and consistent responses to questions. When asked early on in the focus group about sociotechnical engineering, Dorothy expressed that she had heard the term sociotechnical before, but not associated with engineering. Her response indicates internal dialog about sociotechnical thinking since in theory it should be applied to all engineering practices. For Dorothy, there is still a dichotomy of some kind between social and technical thinking: "Yeah, I think I've definitely heard some people mention it, or it's been explained to me in some way, but never with the term 'engineering' at the end of it" (00:11:06).

Throughout the focus group, much of the discussion from Dorothy related social and technical thinking to engineering design. Dorothy pointed out the importance of social impacts on engineering design and of designing products with everyone in mind. The idea that Dorothy relates social considerations to engineering design and creativity shows that Dorothy possesses a basic sense of sociotechnical integration, a level of understanding likely also held by other first-year engineering students. One research team member noted during the debrief after the focus group that Dorothy (and the other focus group participants) had associated sociotechnical thinking with broader design and end-user consequences but had not accentuated broader issues of equity and social justice, including who benefits and who suffers from a particular design.

Dorothy related the importance of thinking about the non-technical in the context of engineering design when she voiced the importance of having non-engineers participate in the design process:

> I think that it's important for design teams to have many different people in the process, not just engineers, or not just the designers or creators of the product, but really everyone else, so you can't just be like, 'Oh, the technical side, we know

> how this works,' but when you ask someone else who's not even close to an engineer, they have a completely different view on what you're making, so it's really important to take in account what they see in your product, or else you could be missing a very important part of your design. (00:12:52)

Dorothy seemed to indicate that she felt sociotechnical thinking could change how one thinks and one's point of view – key parts of their engineering identity – and how one practices when she said,

> I think sociotechnical thinking should be practiced by every engineer… but I think that every engineer right now, even if they've never heard of it, should know about it now for the fact that it really changes someone's way of thinking and it changes points of view and it will change projects, so I think that every engineer should know about this, because it will change how you're going to think about it, and it will change probably your whole design, who knows, but I just think that it is really key in the engineering process. I would say that everyone should use it. (00:55:13)

Dorothy finally discusses 'doing good' and ethics and the importance of engineers wanting to do good, relating this to the social aspects of engineering. Social aspects of engineering seem to register with Dorothy primarily as 'doing good' along with designing and creating for diverse end-users.

> I think that's kind of what drives people to be engineers, because I believe that you're doing something to help people or to improve something, to make things easier. I just think that most engineers like the fact that they're doing the most that they can, and I think the belief that you are doing as much as you possibly can and also helping people is what keeps people going into engineering. (00:21:31)

Dorothy articulates not necessarily a personal identity but a professional one, a conception—perhaps aspiration—of engineers as acting not "for personal gain" but "for the better good." This professional identity is positioned as a career-motivating factor, as "helping people is what keeps people going into engineering."

By contrast, on a personal level, Dorothy indicates that she still does not feel like an engineer. Dorothy discusses a few 'engineering experiences,' but says that identifying as an engineer requires additional education and coursework. Dorothy also discusses the importance of having women in engineering, which help make her feel more welcomed and like an engineer. Her engineering college incoming class in Fall 2019 was 45% women and 55% men, and as a result, it feels like a place where she wants to study engineering:

> [I] do have some engineering experience, but I don't think I could label myself as that because I don't know enough, and I'm not confident enough that I could be like, 'I could go out into the world right now and make a difference,' …. that taking classes that help you think like an engineer, I think that those can make you feel more like an engineer, so in that aspect I think I'm getting there by taking these classes and being able to understand how to think and do projects like engineers… But I think definitely after I

> have my degree and I have more experience under my belt then yeah, I could call myself an engineer. (00:24:28)
>
> ….but if there's that many women, I think that you just have to fight through it and you know it can be done because that many other people who are women are going to do it as well, so it's not just you by yourself. (00:28:23)

Case: Cleopatra

This focus group included seven participants (four male and three female) from the second-year introduction to mechanical engineering course. An interesting trend in this focus group was that many of the participants explicitly connected their identities as engineers to where they were in their engineering curriculum, a finding which is similar to Dorothy's responses and supported by other researchers [26], [28]. For example, when asked whether they identify as engineers, one student, Dakota, answered the question by saying, "…This is a sophomore level class. For the most part, we're just pretty good at math. Most of us haven't really gotten too much into thermodynamics or fluid dynamics, any of that" (00:23:00). One interaction that stood out from this focus group was a disagreement that took place over the integration of sociotechnical aspects into the engineering curriculum and engineering practice. This discord focused on environmental responsibility and if engineers have a role in enacting environmentally responsible designs. Both of these points are highlighted by following one participant, Cleopatra, who played a key role in advocating for the inclusion of sociotechnical thinking into engineering.

Validations of an engineering identity

Cleopatra seemed uncertain about whether she could assume an identity as an engineer. She described receiving the message that, as a sophomore, she didn't yet have the technical knowledge to be identified as an engineer by employers at career fairs: "As soon as they hear you're a sophomore, they kind of shut you down and they're like, 'Well, we'd like to see these classes before we bring you in.' And so, I don't know, it's still frustrating at this point because I feel like, yeah, I put in so much work, but I'm not there yet. So I can't call myself an engineer yet" (00:23:22).

By this statement, she seemed to really be looking to others to identify her as an engineer, rather than looking within herself for her engineering identity [24]. Yet she also said that design classes make her feel "the most like an engineer" (00:24:37), supporting findings from prior work at the intersection of engineering design courses and identity [42], [43].

Traits of an engineer

When asked to describe the personal traits that influence her engineering identity, Cleopatra described "being a good listener" (00:26:46), "being conservative and making sure that you're being very safe about everything" (00:19:17), and "not jumping to conclusions" (00:27:16). She elaborated on this last point: "Like trying to stay away from preconceived notions about something so that you can actually come up with a good design that solves the issues" (00:27:16). She also described the importance of not "over engineer(ing) things" (00:28:56), emphasizing the value of a simpler solution when it's appropriate. She said that engineering involves "a lot of problem solving and looking at the bigger picture" (00:17:33).

A sociotechnical engineering identity

While Cleopatra hesitated to declare that she identified as an engineer, she had a strong and confident sense of what it means to be an engineer and what engineering work should be like. Though she did not explicitly state this, we interpret her identity as squarely a sociotechnical one. When prompted about how important it is for practicing engineers to consider sociotechnical concepts, Cleopatra wondered whether environmental considerations could be a part of sociotechnical engineering, and when the moderator confirmed they could be, she said that she thought that environmental issues are an important component of keeping an engineer's end user in mind. One student, Dakota, said that he believed it is "not really the engineer's responsibility to consider how it effects the environment" (00:41:20), and speculated that this was better suited for the political realm. Cleopatra responded, "I disagree with you so much" (00:41:32). She later explained:

> I think that everyone has a responsibility towards the environment because what we do to the environment affects everyone, and so user-friendly design is inherent in environmentally responsible design. And engineers being the ones to create the devices that can make us more environmentally friendly to society or not, it falls on them, maybe more than others, to think about those things and prioritize that in their careers. (00:45:03)
>
> …Then I also wanted to say that, you said that politicians are the ones who are responsible for those things, but it seems to me that a lot of the progress towards a more environmentally friendly society is done by private firms and engineers who are entrepreneurial and trying to create new things. I don't think we can, but this is getting to something bigger, but the crisis with climate change is too big for us to wait for politicians to lead the charge, and engineers are a big part of the private industry that can put us on the right path. That was my problem with that statement. (00:46:23)

Dakota responded that, "you don't hire an engineer to pass a law, you hire an engineer to accomplish a task, and it's not the engineer's responsibility to decide if it's right or wrong, they were hired to do a job" (00:47:06). Cleopatra replied, "…for each individual engineer as a human being with a life's work to think about, what do you want to contribute?" (00:47:27).

Compared to the other students discussed here, Cleopatra's identity seemed to have less of an inherent liminal quality. She was confident in her identity and knew where she stood as an engineer who values sociotechnical work and understands its importance. Cleopatra's sociotechnical identity drove her to consider the implications of her engineering work on people and on the environment. Rather than being tied to an identity that values solely technical work, Cleopatra declared that sometimes simpler and less technical designs are preferred if they achieve the desired outcome. It is possible that her hesitancy to assume an engineering identity came from the messages she received from others, especially those already in the engineering profession, which seemed to focus on technical knowledge at the expense of other skills and abilities. Her sociotechnical identity seemed most reinforced in her design courses, where she felt “most like an engineer” (00:24:37).

Case: Jay

This Fall 2019 focus group involved four male engineering students enrolled in a third year, required electrical engineering course at University A. The focus group was unique because several forms of evidence indicate that Jay’s engineering identity is in limbo and still under development. Specifically, Jay demonstrated a fair degree of uncertainty about his engineering identity in the following ways: 1) He tended to piggyback on other participants’ statements, rather than offering his own ideas first. 2) He wavered in his viewpoint and held some seemingly contradictory perspectives. 3) He proffered his ideas, then indicated a lack of confidence or certainty.

Evidence of piggybacking

Jay’s focus group comments suggest his engineering identity was wedged between his current identity as an engineering student and his future one as an engineering professional. This liminal engineering identity informs students’ ratings of the utility of the engineering course under question. For instance, some students rated the course according to the degree to which they thought it would directly apply to engineering practice (usually associated with a high rating), or whether the course was less directly applicable to engineering practice (usually a low rating).

We found this to be true across the focus groups investigating all three courses, though it was especially true for the participants enrolled in this third year EE course. For example, in this Fall 2019 focus group, participants rated the course from 30-50 on a 1-100 scale. Bryan, another participant and the first to respond to the question about rating the course, began by rating it as a 50 because he did not see it as useful to his future career, and Jay followed with the same rating for the same reasons. If students’ engineering workplace experience is limited to a single summer internship or less, their understandings of engineering practice can also be expected to be limited, and largely a product of second-hand information drawn from professors, other engineers they know, etc. Thus estimations of the career utility of the course are somewhat speculative at best.

Additional examples of piggybacking emerged. For instance, after Dan said that he sees himself partially but not completely as an engineer because he enjoys problem solving but is not yet particularly qualified, Jay agreed, saying he identified “as an aspiring engineer, hopefully” (00:26:00). This piggybacking pattern from Jay occurred multiple times later in the focus group, too.

Bridging the divide between an engineering student identity and engineer identity may be difficult, particularly if students’ experiences as engineering students lead them to believe that engineering practice will consist (almost) entirely of solving technical problems. Later, Jay elaborated on what engineers do, which he thought to be a question with an obvious answer. He said they “do engineering,” which he went on to define as, “creating solutions to problems given a bunch of different criteria, and usually that's some technical solution to some technical problem" (00:18:06).

This response helps us understand why Jay had expressed at 00:02:53 that "real-world examples" might not apply "to an actual career." It appears Jay's conception of engineering practice is a realm almost entirely focused on technical solutions to technical problems, devoid of social context. Hence, examples with real-world, sociotechnical context might not apply to the narrowly-focused, technical professional realm he perceives he is entering.

Evidence of contradictory perspectives

Jay's technocentric views on engineering practice appear initially to be in contrast to another student's views, namely Bryan's, which place real-world, sociotechnical context front and center because engineers need to have a sense of the "big picture," believing "that what they're doing is for the greater good" and "benefits society." Unlike Jay, Bryan had described engineering as a sociotechnical field where solutions are designed to have real-world, positive impacts on people. It is intriguing that just minutes after describing engineering as "usually [involving] … some technical solution to some technical problem," Jay concurs with Bryan's position on engineering benefitting society, saying, "That's what I was going to say" (00:20:10). He goes on to agree that engineers improve the quality of life for people and/or act for the greater good.

In addition to serving as an example of Jay's piggybacking, this also raises an important question related to a liminal engineering identity: can you have it both ways? That is, can you—as Jay did above—on the one hand agree that engineering has real-world, positive impacts on people, yet also claim that it is a field in which you primarily solve technical problems? Such a stance seems to negate the *sociotechnical inputs* but not the *sociotechnical impacts* of engineering. This contradiction suggests that Jay may reside in a liminal space between his current engineering student identity and his future engineering practitioner identity.

Evidence of engineering identity tentativeness

In relation to his engineering identity, Jay manifests a tentativeness evidenced by markers of self-doubt, largely due to an understandable lack of experience. For instance, when asked about what engineers do, Jay echoes Bryan and ends with a tentative ellipsis, as in these examples: "It's good that we've got all these connections in class to these real-world examples, but I don't know how well that applies to an actual career, I guess…." (00:02:53). Later, he says, "I just haven't really done much of that [worked on actual engineering projects], so…." (00:28:21). After others have addressed the question of engineers' values and attitudes, Jay has not yet said anything, and offers a response indicative of an understandably liminal identity: "Yeah. I don't know. I'm having a hard time coming up with stuff. It's a tough question. Yeah. I don't know. I'm not really sure how to answer that to be honest" (00:31:16).

His response to the moderator's question of whether he identifies as an engineer is equally honest and indicative of his liminal positioning, with words such as "aspiring engineer" and "hopefully": "Yeah. I'd say I identify as an aspiring engineer, hopefully.… And so, hopefully when I graduate I'll be able to apply it, and then I can consider myself an engineer then"

(00:26:00). One exception to piggybacking and tentativeness occurred when Jay contradicted his peers—and seemed to extend beyond his earlier statements about engineering as primarily technical—and indicated that sociotechnical engineering should be integrated into coursework, "at least a little bit in every class…where it could apply" (00:47:44).

Case: Link

Link was chosen for this analysis due to his strong definitive statements about his personal engineering identity and his stance on the role of sociotechnical thinking in engineering education and practice. He established himself as a student looking for "more advanced stuff" beyond the fundamentals of engineering, with an unshakable engineering identity reinforced by his family and prior work experiences. He believed that the appropriate level of sociotechnical integration in an engineering job depends on that position's degree of involvement in the creation of a new design or product. We see Link as an instance of a student with a self-assured engineering identity and an equally assured view of engineering practice, and use him to highlight how some students employ their liminal identities to support their beliefs and expectations about future engineering roles and responsibilities.

Link was the first student out of five total participants in the focus group held during the Spring 2020 semester to respond to the opening question about the value of the third-year EE class, explaining, "I'll give it an 87. For the path I'm taking, this course is very, very useful" (00:00:44). Once all the other FG participants have chimed in with numbers greater than 87, he clarifies, "This is a fundamental class… but there's a lot of nuance details that are not gone over in this class that are more useful to what I look to do in the future…a lot of the more advance[d] stuff is more useful to me" (00:02:25). These statements establish Link as someone who is looking for "more advanced stuff," "in the future," to contrast with those who are focused on first learning the "fundamentals." He is eager to solidify his liminal professional identity by graduating and starting his engineering career, a future where he will apply the "advanced stuff" that the class did not provide for him.

Identity including and beyond engineering

When the focus group moderator asked, "Do you identify as an engineer and why or why not?" Link was again the first to respond, "Yes…pretty much when my family talks about me, they'll always mention, oh, he's in engineering so it's just something that is already there for me, I guess, so it is already something that I would say I identify as**.** Not really something that defines me but definitely something I identify as" (00:17:13). Here, Link is explaining the complex interaction between his personal identity and his engineering identity. Similar to his prior utterances, Link is indicating how he is beyond a simple definition. He also cites "a lot of time working in the field" and the way his family "talks about" him as evidence to support how others identify him as an engineer, "something that is already there for me" – unthreatened and solid. It is not a risk or challenge for him to identify as an engineer. Rather, he emphasizes how he cannot be defined or constrained by engineering.

Sociotechnical thinking as advanced engineering career preparation

The focus group conversation turned to the role of sociotechnical (ST) thinking within engineering courses and the engineering curriculum. Link explained, “It's fine to bring in sociotechnical stuff into the classroom but I do agree technical classes should be more focused on technical work. I see more of the sociotechnical introduced at my 400-level class area where they talk about how you will be using this in your job…When you're doing your basic core classes, I don't think you really need it” (00:45:34). Consistent with his other focus group responses about being personally “advanced” and “beyond” the fundamentals, Link connected ST thinking with advanced coursework. His statements here comparing “technical classes” and “basic core classes” suggest Link’s view of the engineering curriculum starts with 100/200 level core courses that are purely technical, before moving on to upper-division courses at the 300 and 400 level “where they talk about how you will be using this [sociotechnical thinking] in your job.” As his professional identity was not yet formed, he used the sociotechnical content of this upper-division course to justify his expectations and beliefs of what an engineering job will be like.

Dissent over the role of sociotechnical thinking in various engineering jobs: Design vs. testing

When the moderator asked, “How appropriate is it … for practicing engineers to consider sociotechnical concepts when designing engineering solutions?” Link replied:

> I see a lot of that being very dependent on the actual project you're doing because you can be like a test engineer where your entire job is more about just testing, trying to see if it works and trying to figure out all the bugs in the system versus the person who's actually designing it. I do agree it will be irresponsible for the person designing it to not put some thought into that. As far as all walks of engineering go, I believe it's going to be very project and position dependent. (00:48:16)

Two different student participants disagreed with Link’s statements. Roxy responded, “I disagree 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 [if] there's a potential of negative impacts you should be conscious of them and that should always be a thing that you have on your mind” (00:49:59). Baphomet added, “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” (00:50:44). These students opposed Link’s view of professional engineering work, raising questions to collectively explore their liminal future professional engineering identities.

Link attempted to clarify his original statements, adding, “I think you're misinterpreting … A designer has to put a lot more thought versus the guy who's running a systems test or quality control” (00:51:34). Baphomet agreed, saying, “Yeah, I definitely understand … You're just saying, essentially, that your responsibility or the amount that you consider [sociotechnical issues] is scaled by your place in the creation phase” (00:52:36).

This overall exchange demonstrates how students explore their liminal engineering identities before becoming professional engineers, and how they map the importance of sociotechnical thinking onto their future identities based off of their limited experience with engineering design, testing, and manufacturing. If we adopt a typical engineering hierarchy in which design engineers are at the top, with manufacturing, quality, and testing engineers below the rarefied "design" status, then this entire conversation can also be interpreted as another instance of Link describing how he is (or wants to be) *beyond*, more advanced than fundamental, the same pattern he has followed since the beginning of the focus group.

Link provided the example of a "test engineer where your entire job is more about just testing, trying to see if it works and trying to figure out all the bugs in the system." Arguably this phase of product development is where human factors and social considerations would come into play even more than during design, but not in Link's view. Several times in this segment of the focus group all students referred to testing as "just testing" – a minimization of the importance, rigor, and intellectual challenge posed by testing versus design. This view of "just testing" versus design was subsequently challenged by Roxy and Baphomet and defended again by Link when he effectively doubled down on the original statement regarding the relative importance of sociotechnical thinking in the design process compared to testing or other associated engineering product development stages. This could be interpreted as novice engineers discussing a glamorized notion of design versus other engineering roles, simultaneously demonstrating a sociotechnical dualism mindset wherein certain roles need to be aware of sociotechnical considerations, but other roles can easily side-step them. The exchange can also be seen as the students exploring what a professional engineering career will look like, with each person leveraging their prior experience and engineering identity development to convince the other students that their view of the future is more accurate than the others.

Discussion

The original aim of our analysis was to explore how sociotechnical thinking relates to students' identities as engineers, as reflected by their responses in focus groups about sociotechnical integration in one of their engineering courses. In exploring this intersection, we saw evidence of students' liminal engineering identities – meaning, identities that are in limbo. For many of our participants, their current position as students meant that they do not see themselves fully as engineers. Yet they also are not *not* engineers. Their identities are in transition, and the sociotechnical integration that we investigated often served to illuminate this liminal quality of their identities.

Below, we present evidence of liminal engineering identities (or lack thereof) among each of the five cases analyzed. Then we discuss the field of engineering, which is itself also in transition.

Liminal engineering identities

In the case of Becca, clear evidence of a liminal identity emerged. In Becca, we see a student who identifies traits that she believes make her an engineer ("how I look at situations and how I think about things," "creative writing," and reading fantasy), and yet she also wrestles with whether these same traits actually fit within engineering. She contrasts them with being "very logical, math- and science-oriented," the stereotypes of engineers. We see Becca refer here to traits that are broadly seen as important for engineers to possess, and that are also used in engineering education research to measure engineering identity (e.g. in [26]). We see that the traits that Becca identifies in herself put her in a liminal space, causing her to both identify as an engineer and not identify as an engineer within the same focus group. Becca occupies a liminal space in part because stereotypes about what and who engineers are appear to circulate and/or be reinforced in her present environment.

Dorothy has a strong sense of what she would like engineering to be like: "doing something to help people or to improve something" (00:21:31). She has a strong aspirational sense of what she thinks the profession should be like, yet she hesitates to adopt an engineering identity because of what she perceives to be a lack of experience and knowledge. Like Becca, Dorothy also finds herself in a liminal space in that she has views of what engineering can and should be like – views focused much more on one's motivations and social contributions – yet she resists seeing herself as an engineer because she feels she doesn't (yet) fit within the current mold of engineering as focused on one's knowledge and abilities. Her aspirational engineering identity, she believes, will come with more time and coursework. For now, she indicates that she feels more like an engineer due to the unusually high percentage of women in her engineering college.

Like Becca, Cleopatra has a strong sense of the traits she possesses that align her with an engineering identity – traits that are sometimes at odds with the view that engineering is a solely technical undertaking. However, Cleopatra is confident that her sociotechnical skills can support her engineering identity, in part because her experience in design courses proved this to be true. By contrast, Becca felt that her love of creative pursuits was a barrier to adopting an engineering identity. For Cleopatra, her identity was only called into question when external actors, like recruiters at a career fair, questioned her position as an engineer because, as a sophomore, she had not yet had upper-division engineering courses. Thus, we see outside forces placing Cleopatra in a liminal space that she herself did not know she occupied. Cleopatra's liminal identity also includes some pushback on traditional engineering identity stereotypes. She notes that she is developing some important, and perhaps less stereotypical, traits of engineers such as listening skills, a safety mindset, and "looking at the big picture" (especially the environment). Cleopatra sees herself as not yet an engineer, but on the road to becoming one.

In Jay, we see a liminal identity emerge when he holds two seemingly contradictory views of what the field of engineering is like. He describes engineering problem-solving as "some technical solution to some technical problem" (00:18:06), yet soon after also agrees that engineering is a field which positively impacts people. To him, the connection is obvious (a technical solution, by its very nature, benefits society, in his view), and he seems unaware that there is a rich sociotechnical context to such impacts. His own engineering identity is also between two places, when he describes it as aspirational. Despite his depiction of engineering as primarily technical, he also sees the value of integrating sociotechnical engineering "a little bit in every class…where it could apply." Thus, we see both Jay's engineering identity and his views of engineering practice as liminal.

Finally, we also see connections between Link's engineering identity and his views of engineering practice, but Link is more secure and confident in his views than Jay. Link is certain in his engineering identity and feels he knows with certainty what engineering practice is like.

Although he indicates that technical courses should focus primarily on technical work, he also associates sociotechnical engineering with advanced, senior-level coursework, which he believes include situated discussions of workplace or other real-world applications of engineering knowledge. He acknowledges that engineering can be a sociotechnical undertaking, but he also believes that this depends on the role that an engineer holds in a project, differentiating between design engineers, whose work is sociotechnical, and test engineers, who he thinks have no sociotechnical aspects to their work. Across the five students analyzed in this paper, Link's engineering identity is by far the most self-assured and established and the least liminal. His views of sociotechnical engineering are similarly established and without question.

The field of engineering in transition

Engineering as a field also currently occupies a liminal position, caught between two versions of itself. High-profile publications like the National Academy of Engineering's "Engineer of 2020" report [40] and the ABET accreditation criteria [44] point to a need to revolutionize how we teach engineering students and how we determine what counts as important engineering skills and abilities. Engineering practice similarly has been repeatedly found to acknowledge and work within sociotechnical contexts [1]–[3]. Yet engineering practice and policy documents, on the one hand, and engineering curricula, on the other, largely continue to differ with respect to sociotechnical integration. Curricula continue to reflect technical-social dualism, despite efforts to integrate the sociotechnical elements of engineering practice into the classroom [6], [8], [12]. Each of the focus group participants described in this paper seemed, to varying degrees and in different ways, to sense this liminality and wrestle with the question of what engineering really *is*.

When it comes to teaching sociotechnical thinking, it is possible that perceptions of this skill may place it squarely on one side of this transition that engineering is currently faced with: the not-yet-here, aspirational version of sociotechnical engineering practice and education. We propose that this may make it harder to teach sociotechnical thinking to our students, since it contradicts the views that many of them and those around them (including their professors) hold about what engineering is. The liminality of engineering as a field may also make it harder to convince other engineering education stakeholders about the need for widespread adoption of sociotechnical thinking, since it may appear we are pushing a novel pedagogy which attempts to shape engineering into something new. By contrast, we see our work on teaching sociotechnical thinking as acknowledging and teaching toward what engineering actually and already is.

Conclusion

This work explores how students' conceptions of engineering identity are linked to their perceptions of sociotechnical thinking. To understand how these two are related, we used a case study framework looking at individual participants across five focus groups. From this analysis, the theme of liminal engineering identity – an identity which is in limbo between two distinct positions – emerged as a powerful lens for understanding how students saw themselves and their future selves in relation to engineering practice and sociotechnical thinking.

The case study method is not intended to generate generalizable results. Thus, the scope of our findings, which some may see as a limitation of our findings, is also a strength of this work. This analysis allowed us to focus on the individual, lived experiences of these five students alongside the other participants in their respective focus groups. Such deep qualitative dives into student perceptions yield insight into their own evolving, liminal identities. The findings from this paper will add to the growing literature on engineering identity and on scholarly inquiries of curricular efforts to render visible the interplay between the social and technical dimensions of engineering problem solving.

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Appendix: Semi-Structured Focus Group Protocol

1. What score on a scale from 1 to 100 with 100 being the most useful undergraduate course and 1 being the least useful undergraduate course: How would you score this course?
    a. Tell us more about what impacts that score? (What elements of the course did you consider when determining that score?)
2. Have you heard the phrase “sociotechnical engineering” previously?
    a. Have you heard it in the context of (GEEN1400/MEGN200/EENG386)? What about your other engineering classes?
    b. What does it mean to you?
3. Tell me some words or phrases that describe what you think practicing engineers do, think, and believe.
4. Do you identify as an engineer? Why or why not?
5. What values or attitudes do you hold that influence your identity or lack of identity as an engineer?
6. What did you learn in your (GEEN1400/MEGN200/EENG386) course, which you did not previously know, regarding sociotechnical elements of engineering?
7. How did your (GEEN1400/MEGN200/EENG386) instructor convey the concept of sociotechnical engineering?
    a. What could your instructor have done to better prepare you as an engineer to consider sociotechnical elements of engineering?
8. How appropriate is it for engineering professors to teach sociotechnical concepts in technical engineering courses?
9. How appropriate is it for practicing engineers to consider sociotechnical concepts when designing engineering solutions?
10. (Added in 2020, on paper) If you are willing , please tell us the following demographic information about yourself to help us improve the research results: Gender, Race/Ethnicity, Major, Minor, Year in School, Expected Graduation Year, University, Transfer Student, International Student Status. Please tell us if any of this information is likely to identify you to your professor or others so that we can maintain your anonymity.