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”You Could Take ’Social’ Out of Engineering and Be Just Fine”: An Exploration of Engineering Students’ Beliefs About the Social Aspects of Engineering Work

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“You could take ‘social’ out of engineering and be just fine:” An exploration of engineering students’ beliefs about the social aspects of engineering work

Abstract
Engineering is both a social and technical discipline, and engineering students encounter the social aspects of engineering work in a variety of education and internship contexts. These education and internship experiences inform engineering students’ beliefs about the social aspects of engineering work and thus influence the practice and outcomes of their work. To better understand the variety of beliefs that engineering students may possess about the social aspects of engineering work, we conducted interviews with 30 upperclassmen engineering students. Participants were provided with eight statements related to the social and technical aspects of engineering work. They were then asked to pick two statements that aligned most with their experiences and two that aligned less well. Focusing on the social elements that students discussed, fifteen out of 30 participants selected “Engineering is a social discipline” as aligning *less well* with their experiences, in part because they interpreted “social” to be about social bonding and felt that it was separate from, and unnecessary to, effective collaboration. Seventeen out of 30 participants also selected “Engineering is a team discipline” as a statement that aligned *well* with their experiences and identified collaboration and communication as core aspects of engineering work. Discussions of other social aspects of engineering, such as engaging with stakeholders, collaborating with users, or considering the societal implications of engineering work, were relatively limited. Understanding engineering students’ beliefs about the social aspects of engineering work based on their previous experiences can help us better align engineering curricula to promote more holistic and inclusive views of engineering.

1. Introduction

Engineering is an inherently social discipline. The social aspects of engineering work include the various ways that engineers, within the context of their professional roles, impact, interact with, and relate to both broader society and other individuals. For example, engineering work produces significant and long-lasting impacts on society, and engineers are responsible for understanding the potential societal implications of their solutions [1]–[4]. As another example, engineers may work closely with communities and stakeholders as part of their problem definition and solution development processes [1], [4]–[6]. Furthermore, communication and collaboration are core aspects of professional engineering practice. To achieve optimal engineering outcomes, engineers must be able to work effectively with diverse teammates and co-workers [1], [7]–[9].

Engineering students engage with the social aspects of engineering work in several contexts, including internships and project-based design courses. However, previous studies have observed variations and gaps in the ways that engineering students conceptualize the social aspects of their work. For instance, some engineering students may consider stakeholder engagement to be a core aspect of engineering practice, while other engineering students may view this engagement to be largely unnecessary [10]–[12]. Engineering students may also vary substantially in the degree to which they consider the broader societal contexts of their engineering problems [13]. Furthermore, some engineering students may conceptualize engineering work as being purely technical and may thus struggle to apply “non-technical” knowledge and approaches when developing engineering solutions [4], [14]. In part, these variations and knowledge gaps may emerge because strong, intentional education about the social aspects of engineering work is not often included within standard undergraduate engineering curricula [4], [15], [16].

Our preliminary study investigated junior- and senior-level engineering students' beliefs about the social aspects of engineering work based on their previous education and internship experiences. Students' beliefs about engineering work represent an important research topic because of how these beliefs may influence engineering practice and outcomes [1], [17]. Specifically, in the context of this study, the investigation of students' beliefs can deepen our understanding of how engineering students may think about and apply knowledge related to the societal contexts of their engineering work. The investigation of students' beliefs can also provide insight into the specific ways that engineering students may be perpetuating normative conceptions of engineering work as being separate from social concerns and/or unintentionally contributing to existing systems of inequality or exclusion within engineering environments. Studying students' beliefs in the context of their previous experiences further enables us to explore how students may acquire their beliefs about engineering work, and thus can inform pedagogy that supports engineering students in developing more inclusive views of engineering.

2. Background

2.1 Social aspects of engineering work: Engineering *with*, *for*, and *as* people

There are several ways to conceptualize the social aspects of engineering work. One useful framework, which forms the basis for our later analysis, is the "engineering *with*, *for*, and *as* people" framework described by Fila et al. [1]. This framework does not encompass all social aspects of engineering work: for instance, it does not discuss in depth the systems-level interactions between engineering work and the broader social, political, environmental, and/or economic contexts within which this work occurs. However, this framework does provide a clear summary of key ways that engineering is a social discipline in addition to a technical discipline.

Engineers work *with* people. Engineering *with* people involves collaborating with stakeholders and communities to produce successful and equitable engineering outcomes. In engineering domains such as product or service design, stakeholders represent valuable sources of information that can help engineers understand the goals of their engineering work and evaluate the feasibility of potential solutions [18], [19]. Case studies such as Luck [5] and Østergaard et al. [20] also show that, through participatory or co-creative techniques, engineers can leverage the unique knowledge of stakeholders in the development of innovative solutions. Stakeholder engagement skills thus represent important knowledge for engineers to develop, although this knowledge is not typically covered as part of standard engineering curricula [15], [16].

Engineering *with* people also includes the teams and organizations within engineering working environments. Trevelyan [7], [8], in his studies of professional engineering practice, observed that engineers spend a significant portion of their working time communicating and coordinating with teammates and co-workers. Olson et al. [21] and Bucciarelli [22] have similarly observed that engineers spend substantial time during technical meetings clarifying ideas to teammates and coordinating their projects. Passow and Passow [9], in their review of literature related to core engineering competencies, highlighted collaboration skills as a crucial component of technical competence. Anderson et al. [23], based on their investigation of engineering practice at six engineering firms, further suggested that some professional engineers consider communication and coordination skills to be the most important skills that they leverage to complete their work.

Engineering work should also be *for* the benefit of people and society. For instance, the Accreditation Board for Engineering and Technology (ABET) [2] states that engineering graduates must be able to "apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors." Professional societies such as the National Academy of Engineering [3] and the National Society of Professional Engineers [24] also emphasize service to society as a core mission of engineering. The phrase "engineering *for* people" thus captures the aspirations of the engineering profession, especially if engineers can successfully engineer *with* stakeholders and communities. However, as described by Nieusma and Riley [6], engineers who work *for* people but not effectively *with* people risk perpetuating existing social inequities.

Lastly, engineers work *as* people, meaning that their personal and social identities influence their engineering work. Previous studies have documented how various aspects of engineers' personal and social identities, including domain background [22], [25], psychological characteristics and personality [25], [26], race [25], [27]–[30], gender [25], [30], [31], socioeconomic status [25], [28], [32], and ability status [33], [34], may affect the ways that engineers interact with other engineers or stakeholders and/or apply their knowledge to solve problems. Engineering *as* people also refers to how engineers' ideas about "legitimate" engineering work may influence their work processes. For instance, Cech [17] has suggested that, due to a culture of "depoliticization" in engineering, engineers may view their personal, social, and cultural values as disconnected from their engineering work and thus may not consider the implications of their positionality when engineering *with* or *for* people.

2.2 Engineering students' beliefs related to the social aspects of engineering work

Previous studies have described several beliefs that engineering students may possess about engineering work and the role of social or societal considerations within this work. For example, Khosronejad et al. [14] studied how engineering students approached a simulated design task related to air pollution mitigation. They found that participants rejected solution ideas involving policy initiatives or stakeholder education because these solutions did not align with participants' conceptions of engineering work as the creation of physical artifacts. Studies such as Cech [35] and Bielefeldt and Canney [36] have also reported that engineering students' feelings of social responsibility may decline over the course of their undergraduate engineering education. Cech [35] attributed this decline to a "culture of disengagement" in engineering education, i.e., a widespread belief that public welfare considerations are tangential to engineering work. As a result, engineering students may not view potential societal impacts as important factors to consider in the development of engineering solutions, although Rulifson and Bielefeldt [37] have shown that students' attitudes about social responsibility may also be positively influenced by community-engaged, co-curricular projects and/or courses on engineering ethics.

Other studies have explored the relationship between engineering students' beliefs about engineering work and their approaches to interacting with stakeholders. Niles et al. [4] suggested that some engineering students may struggle with the stakeholder engagement aspects of engineering work because these practices seem to conflict with the technocentric focus of traditional engineering education. In addition, Zoltowski et al. [10] described a continuum of potential engineering student perspectives related to stakeholder engagement ranging from "Technology-centered" (i.e., no stakeholder involvement in design projects) to "Empathic design" (i.e., deep stakeholder involvement and relationship building). Building on this work, Loweth et al. [11], [12] observed that engineering students' perspectives on stakeholder engagement seemed to influence the techniques that students used to engage stakeholders in their design projects, as well as the frequency of their engagements.

Studies have also explored beliefs that engineering students may possess related to working or interacting with other engineers. For instance, Meyers et al. [38] surveyed engineering students about the factors that they believed were necessary to be considered an engineer. Participants in their study consistently selected "Being able to work with others by sharing ideas" and "Speaking/communicating using accurate technical terminology" as key descriptors of engineers. In contrast to these findings, Dunsmore et al. [39] reported that their engineering student participants described teamwork as an obstacle to be overcome rather than as a fundamental characteristic of engineering practice. Meanwhile, Litchfield and Javernick-Will [40], in their study of engineering students' engineering identities, found that engineering students who saw themselves as outgoing and/or interested in engaging with others also described these qualities as being atypical of engineers. These studies collectively suggest that there are a variety of ways that engineering students may conceptualize their interactions with other engineers, and thus also likely a variety of ways that students may approach interactions with other engineers in practice.

3. Methods

3.1 Research Questions

While previous studies have identified potential ways that engineering students may conceptualize the social aspects of engineering work, our study sought to understand students' beliefs in greater depth and also identify specific ways that students' beliefs may be informed by their education and work experiences. Our study was guided by the following research questions:

1. What ideas related to the technical and social aspects of engineering work do engineering students feel align most and align least with their education and internship experiences?
2. When interpreting their previous experiences, how do engineering students describe the social aspects of their engineering work?

3.2 Participants

Thirty junior- and senior-level engineering students were recruited to participate in our study. Participants were recruited through a study solicitation and screening survey that was sent to university listservs in the Mechanical Engineering, Industrial and Operations Engineering, and Electrical Engineering/Computer Science departments at a large Midwestern university. We recruited participants from multiple engineering departments so that we could explore a range of potential disciplinary experiences. The screening survey collected basic demographic and contact information, and we leveraged stratified sampling (based on race, gender, and major) to maintain diversity in the collection of students that we invited to participate in interviews. Eighteen out of 30 participants in our final participant sample reported identifying as White, seven participants reported identifying as Asian American, three participants reported identifying as Black, and two participants reported identifying as multiracial. Fifteen out of 30 participants reported identifying as men, 14 participants reported identifying as women, and one participant reported identifying as non-binary. Academic information for our participants is included in Table 1. We have aggregated our participant data to conceal the identities of our participants, some of whom might be highly identifiable within their disciplines due to low overall diversity.

Table 1. Aggregate academic information for participants

Category	*n*	%
Total	30	100
Class Standing		
Junior (3rd year)	9	30.0
Senior (4th year)	20	66.7
>4th year	1	3.3
Major*		
Mechanical Engineering	11	36.7
Electrical Engineering	11	36.7
Industrial and Operations Engineering	6	20.0
Computer Science	3	10.0
Biomedical Engineering	1	3.3

*Two participants indicated more than one engineering major

3.3 Synthesizing technical and social aspects of engineering work

In preparing the interview protocol for our study, we generated eight statements that captured key ideas related to the technical and social aspects of engineering work (shown in Table 2). We synthesized these eight statements from descriptions of engineering work found in reports published by engineering organizations (e.g., the National Academy of Engineering [3], [41]–[43]) and universities with an engineering focus (e.g., the Massachusetts Institute of Technology [44]), as well as the academic literature (e.g. Passow and Passow [9]). We conducted pilot interviews with engineering practitioners to verify that our eight statements aligned with practitioners' perspectives of engineering work.

Our eight statements encompassed multiple ways that engineering is both a technical and social discipline. Statements such as "Engineering is a technical discipline" and "Engineering is a social discipline" highlighted these aspects of engineering work explicitly. Other statements communicated ways that engineering is simultaneously technical and social. The statement "Engineering is a team discipline" reflected the idea that engineers frequently collaborate to complete technical tasks. The statements "Engineering is a global discipline" and "Engineering makes the world a better place" were grounded in the idea that engineers' technical design decisions have far-reaching impacts on society. The statement "Engineering is about synthesizing and integrating knowledge" related to how engineers utilize both social and technical information to inform their design decisions. The statements "Engineering is a creative discipline" and "Engineering is constantly evolving" reflected how engineers' technical processes are flexible, iterative, and adapting in response to societal changes.

Table 2. Statements about engineering work synthesized from literature

Statement about engineering work	Definition	References
Engineering is a technical discipline.	Engineers use math and science to solve problems.	[2], [3], [9], [24], [41]–[49]
Engineering is a social discipline.	Engineers solve problems that impact people. These interventions inevitably have intended and unintended impacts on societies.	[2], [3], [24], [41], [42], [44], [47], [49]
Engineering is a global discipline.	The world is increasingly interconnected. Technology is developed by diverse teams and can have far-reaching impacts on diverse stakeholders.	[2], [3], [24], [41], [44], [47], [48], [50]
Engineering is a team discipline.	No individual can possess all of the technical expertise required for the complexity of modern engineering problems, and some essential knowledge for engineering practice is unwritten/implicit and can only be accessed through collaboration.	[2], [3], [9], [24], [42]–[48]
Engineering is a creative discipline.	Engineers explore unstructured problems and identify multiple paths to solutions.	[2], [3], [9], [45]–[48]
Engineering is constantly evolving.	Advances in knowledge are so rapid that even the fundamentals of engineering are no longer fixed. Engineers need to continue learning throughout their careers to keep up with changes in technologies and the contexts in which they are used.	[2], [3], [24], [41], [45]–[48]
Engineering is about synthesizing and integrating knowledge.	Engineers solve complex problems by synthesizing information and approaches from STEM and non-STEM disciplines.	[2], [3], [9], [24], [41]–[49]
Engineering makes the world a better place.	The goal of making the world better for all people through engineering is both historical and aspirational.	[2], [3], [41], [44], [47]

3.4 Data collection

We conducted and audio-recorded a single 60 to 75-minute interview with each study participant. The first 22 interviews were conducted in person, and the remaining eight interviews were conducted over a video-conferencing software such as Zoom. During interviews, we provided participants with the eight statements about engineering work shown in the left-hand column of Table 2. Since our goal was to understand participants' genuine conceptions of engineering work based on their own experiences, we intentionally did not provide definitions for each statement. Rather, we encouraged participants to interpret each statement in ways that made sense to them, and to discuss experiences that aligned with their personal interpretations.

Before providing our eight statements about engineering work to participants, we first clarified the goal of the exercise: participants would be asked to select two statements that aligned most with their previous engineering experiences. Our process for providing our eight statements to participants then differed slightly between in person and remote interviews. During in person interviews, we printed each statement on individual slips of paper. The interviewer read these slips aloud one-by-one before handing each slip to the interviewee. Participants were free to arrange the eight slips as desired while thinking through their responses. During remote interviews, the interviewer sent participants the full list of eight statements via the software's chat function, and then read out the statements one-by-one. We did not notice differences in how participants' thought through their responses between in person and remote interviews.

After providing our eight statements to participants, we asked participants to select two statements that aligned most with their previous engineering education or work experiences. Once participants made their selections, we then asked participants to describe a story from their experiences that aligned with one of their selected statements. As participants shared their stories, we asked follow-up questions to clarify how participants connected their stories to their first selected statements. We repeated this process for participants' second selected statements.

We transitioned to the second part of our interview by clarifying that we would be using the same eight statements for a new exercise. We then asked participants to select two statements that aligned less well with their previous experiences and to discuss their rationale. We asked participants to discuss their rationale (rather than provide an example experience) because in many cases participants chose statements that had not played a significant role in their education and work experiences. However, participants were encouraged to share an experience that did not align with their chosen statements if they were able. Similar to the first part of the interview, we asked follow-up questions to clarify how participants interpreted each selected statement and how they connected these statements to their experiences (or lack thereof). Participants were allowed to choose statements that they had previously discussed as aligning with their experiences, but only one participant discussed the same statement twice. Recordings of interviews with participants were transcribed, and these transcriptions were checked for accuracy by a member of the research team.

3.5 Data analysis

To answer our first research question, we recorded the statements about engineering work that each participant selected as aligning most and aligning least with their education and internship experiences.

To answer our second research question, we analyzed participants' interview responses to identify specific ways that participants described the social aspects of engineering work.

First, two researchers reviewed participants' justifications for the statements that they selected as aligning most and aligning least with their engineering experiences. During this review, the researchers identified representative quotes that captured the main ideas or experiences shared by each participant. The two researchers also recorded, for each quote, the statement about engineering work that had elicited the quote. After completing this initial review, the two researchers grouped together quotes that conveyed similar experiences and/or ideas about engineering work and defined the central idea communicated by each group of quotes. An example of this grouping process is shown in Table 3. Building upon work by Godfrey and Parker [51] and Schein [52], we titled these central ideas collectively as "beliefs about engineering work." The two researchers then reviewed participants' interview responses again to identify additional participant quotes that had been missed during the initial round of review and that aligned with one of the identified beliefs. After completing this second review, the two researchers discussed discrepancies in their understandings of each identified belief, iterated on their definitions of these beliefs, and reached complete negotiated agreement as to the prevalence of each belief across participants' responses.

Our analysis process identified a diversity of beliefs about engineering work across participants. Beliefs about the social aspects of engineering work, particularly engineering *with*, *for*, and *as* people as defined by Fila et al. [1], are reported in our findings. Most of these beliefs related to engineering *with* and/or *for* people. Participants discussed few beliefs that were directly related to engineering *as* people in reaction to our eight statements.

Table 3. Example of coding approach

Quotes from participants	Belief about engineering work
"*You'll get a lot farther if there's a group versus just one person trying to figure it out by themselves… Different people bring different things that can build on each other and make it into something good.*" (Participant 25) "*When we were doing data collection, data analysis, it was helpful to have multiple people for multiple ideas. Some people in the group noticed one thing that was significant in the data and another person would find something else in terms of patterns and discrepancies*." (Participant 19)	Engineering teams comprising diverse perspectives are more likely to develop successful engineering solutions than single engineers working alone

4. Findings

4.1 Statements about engineering work that aligned most and least with engineering students' education and internship experiences (answering RQ1)

Table 4 provides a summary of participants' choices for statements about engineering work that aligned most and aligned least with their experiences.

Table 4. Summary of participant choices for statements about engineering work that aligned most and aligned least with their education and internship experiences

Statement about engineering work	Align Most	Align Least
Engineering is a team discipline	17	1
Engineering is about synthesizing and integrating knowledge	15	5
Engineering is constantly evolving	7	10
Engineering is a technical discipline	5	2
Engineering makes the world a better place	5	9
Engineering is a creative discipline	4	10
Engineering is a social discipline	4	15
Engineering is a global discipline	3	8

Two statements were selected by at least half of our participants as aligning most with their education and internship experiences in engineering: “Engineering is a team discipline” (17/30 participants) and “Engineering is about synthesizing and integrating knowledge” (15/30 participants). After these two statements, the next most frequently selected statement was “Engineering is constantly evolving” (7/30 participants). The remaining five statements were each selected by five or fewer participants as aligning most with their engineering experiences.

The most common statement selected by participants as aligning less well with their engineering experiences was “Engineering is a social discipline,” selected by 15 out of 30 participants. Other statements that were selected by at least a quarter of participants as aligning less well with their experiences included “Engineering is constantly evolving” (10/30 participants), “Engineering is a creative discipline” (10/30 participants), “Engineering makes the world a better place” (9/30 participants) and “Engineering is a global discipline” (8/30 participants). The remaining three statements were each selected by five or fewer participants as aligning less well with their engineering experiences.

4.2 Engineering students’ beliefs about the social aspects of engineering work (answering RQ2)

Participants described a variety of beliefs about engineering work when discussing their selected statements. In this section, we report beliefs related to social aspects of engineering work that recurred across participants.

Participants discussed several beliefs related to working *with other engineers*, particularly in the context of statements such as “Engineering is a team discipline,” “Engineering is about synthesizing and integrating knowledge,” and “Engineering is a social discipline.” These beliefs included: 1) collaboration with other engineers is an important part of successful engineering work, 2) effective communication is an important part of successful engineering work, and 3) personal friendships with teammates are not important for effective collaboration.

Fifteen out of the 17 participants (nine men, six women) who selected “Engineering is a team discipline” as aligning most with their experiences did so because they felt that collaborating with other engineers enabled them to achieve more successful engineering outcomes. In the words of one such participant:

“*I've found that if I don't work with others I won't be as successful. Even in classes that aren't project focused or team-oriented, I've found that just working with other people and clarifying things you maybe don't understand in lecture and just studying together [can be] overall beneficial. People can usually accomplish more as a group than individually… If I had to do everything myself, it would not get done.*” (Participant 22)

Ten of these 15 participants (five men, five women) additionally emphasized the value of including diverse perspectives within their engineering collaborations. For example:

“*People with different backgrounds can talk about and critique different things. That's always really useful, especially in a creative setting for brainstorming as well as design reviews, seeing if you have any glaring issues that maybe made sense to you but to someone else just doesn't work.*” (Participant 2)

As illustrated by this quote, several participants perceived clear benefits in including diverse engineering perspectives in their engineering work, particularly because engineers with different backgrounds might identify different types of potential problems. Other participants similarly emphasized that engineers with diverse perspectives might identify different types of solutions during ideation activities and/or contribute different and complementary types of knowledge during solution development.

Participants also discussed the role of communication in working with engineers. For instance, when discussing how "Engineering is a team discipline" aligned with their experiences, six participants (four men, two women) stressed that effective communication with teammates was a necessary part of engineering work:

"[Engineering] is about communication, and not just being technically skilled. Being able to explain to your other teammates what you're doing and also what you need from them to make your project integrate with everyone else… you have to speak up and be clear about where you're at so that everyone's on the same page." (Participant 24)

As described by this participant, engineers need to communicate effectively as part of their work to ensure that team members possess equivalent understandings of the project and can properly integrate their work outcomes. Five other participants (two men, three women) similarly stressed the importance of effective communication with teammates during discussions of "engineering is about synthesizing and integrating knowledge" and "engineering is a social discipline."

Five participants (one man, four women), during discussions of "engineering is about synthesizing and integrating knowledge" and "engineering is a social discipline," further emphasized the importance of effective communication for gathering needed information. As explained by one participant:

"*I've been repeatedly told engineering is about how you talk to people, what knowledge you get out of them, and then how you put that knowledge together, more than it is about being a genius or being super creative… A lot of learning in engineering is, how do you say it? Oratory? It's passed down. It's not documentation. Of course, you're encouraged to have documentation, but that's not how the real world usually works… It's really important that you talk to people and synthesize everything you learn from them.*" (Participant 5)

In other words, relevant engineering knowledge is often distributed across individuals rather than available through a central resource or database. As such, engineers should be able to gather needed information from multiple individuals and synthesize this information as part of their engineering work.

Participants mainly interpreted the statement "Engineering is a social discipline" in terms of interpersonal interactions between engineers. Seven out of 15 participants (two men, four women, one non-binary) who said that this statement aligned less well with their experiences emphasized that personal friendships were not a prerequisite for collaborating effectively with other engineers. As described by one participant:

“*I feel like engineering classes aren't made to be social and interactive at all. They are meant to be collaborative, which is why I do believe that engineering is a team discipline, but not necessarily social in the way where I see interpersonal relationships as defining the work that you do…And while I believe teams do better when there's common ground and social interaction… I don't think it is a prerequisite in order to do your work… I think collaborating and being able to communicate or being able to read a room is really important, but I don't think social is, like your ability to ‘bond’ or ‘get along’ with your teammates, because there's very few people I talk to in my classes.*” (Participant 15)

One of the ways that this participant distinguished between “social” and “collaborative” activities in engineering was by referencing their curricular environment: most of their engineering classes were meant to be collaborative (i.e., encouraging teamwork), but not necessarily “social” (i.e., encouraging friendships between students). Participants discussed other ways that their engineering education and work environments seemed to discourage “social” behavior as well. For instance, four participants (three men, one woman) described team project experiences that involved limited interaction with teammates beyond what was necessary to complete their projects. Three participants (two women, one non-binary) described research or internship experiences that involved working alone at a desk with minimal interaction with other engineers. Furthermore, two participants (one man, one woman) discussed how the competitive nature of engineering classes tended to discourage social behavior. These various experiences provided additional reasons that participants in our study felt that the statement “Engineering is a social discipline” did not align well with their experiences.

In addition to beliefs about working with other engineers, some participants also discussed beliefs related to the social impacts of engineering work. Discussions of social impacts most consistently occurred in the context of the statement “Engineering makes the world a better place.” For example, seven participants who selected the statement “Engineering makes the world a better place” discussed how the goal of engineering work is to improve society, such as in the following quote:

“*Engineering has improved a lot of aspects of life over the past 100 years, whether that's transportation, healthcare… Using technology to find solutions is definitely something that I see that engineering does and that's why I really enjoyed my time here [in college], working on projects that I feel can have that type of impact, and that's what I'm looking forward to doing in the future as well.*” (Participant 14)

This participant felt that the outcomes of engineering work have improved many aspects of society, which is why this participant felt that engineering did indeed make the world a better place. Including this participant, three of the seven participants (all men) who discussed improving society through engineering felt that “Engineering makes the world a better place” aligned with their experiences. The other four participants (one man, two women, one non-binary) felt that “Engineering makes the world a better place” did *not* align well with their experiences; these four participants described improving society as an aspiration rather than as a reality of engineering work.

Other beliefs related to the social impacts of engineering work that recurred in our data were: 1) engineers should consider the broader societal implications of their engineering work and 2) engineers should consider the needs of their stakeholders. For instance, the following quote from a student who felt that "engineering is a social discipline" did not align well with their experiences relates to the consideration of broader societal implications:

"*It is important to realize how the stuff that you do could affect the community that you live in or the people that you are actually doing it for. I feel like it might be easy to forget while you're in engineering that what we're trying to do is generate power for the people and for your own families. I feel it's important to take a step back instead of just focusing on specific project or specific technicalities that you're working on.*" (Participant 25)

However, participant quotes related to the consideration of broader societal implications and/or stakeholders in engineering work were scattered across statements rather than occurring in response to any particular statement. In other words, although several participants seemed to believe that engineers should consider broader societal implications and stakeholders, none of our eight statements consistently elicited discussions from participants related to these beliefs.

4.3 Case example of a single engineering student's descriptions of working with other engineers (answering RQ2)

In total, 28 out of 30 participants discussed beliefs related to working with other engineers, particularly in the context of "Engineering is a team discipline," "Engineering is about synthesizing and integrating knowledge," and "Engineering is a social discipline." This section of our findings delves into the specific experiences and beliefs of one of those participants (hereafter referred to by the pseudonym of Susan), who reported identifying as a White woman. This participant was selected as a case example because she was one of three participants who selected both "Engineering is a team discipline" and "Engineering is about synthesizing and integrating knowledge" as aligning most with their engineering experiences, as well as "Engineering is a social discipline" as aligning less well with their experiences. While this specific case does not reflect the perspectives of all students in this study, it does provide important additional context that illustrates in greater depth how some of our participants seemed to conceptualize the differences between "social bonding" and "collaboration."

"Engineering is about synthesizing and integrating knowledge" was the first statement selected by Susan as aligning most with her engineering experiences. When discussing this statement, Susan described an internship experience where her company tasked interns with developing an engineering solution to a business problem as part of an internal competition. Susan felt that this experience demonstrated the statement "Engineering is about synthesizing and integrating knowledge" because she was required to gather relevant information from a variety of sources and synthesize this information to develop an effective product. As she described:

"*A lot of what we did in the group was pull together all of the different experiences we'd had in industry and in classrooms, and in our extracurriculars, and in our own readings in free time. Then, we combined [these experiences] with knowledge and information that we gained from user interviews and the business managers, and our problem statements and everything… and analyzed [this information] to really build something that had the potential to be useful… That* *whole process of taking all of your past knowledge and all of the situational knowledge that you can gather and coming up with a new idea to solve a problem is something that I've seen repeated through all of my different engineering experiences.*"

As part of this experience, Susan identified two different types of individuals from whom engineers may gather information related to their engineering work: users and business managers. By specifying "interviews," Susan also indicated that engineers gain information about users through direct interaction. This quote thus relates to other participants' discussions about the need to communicate effectively with other individuals as part of engineering work, while additionally highlighting the importance of communication with non-engineers as well.

"Engineering is a team discipline" was the second statement selected by Susan as aligning most with her engineering experiences. Susan felt that this statement was exemplified by her experiences volunteering annually as part of a high school STEM competition. As described by Susan, the role of the volunteers was to support competitors in working through technical difficulties that they encountered while setting up their projects. Each of the volunteers brought unique skill sets (e.g., some volunteers were better at programming, while others were better at wiring or pneumatics) and volunteers coordinated closely to provide an optimal level of technical support across all teams participating in the competition. This coordination aspect of her volunteering experience was particularly salient for Susan:

"*I picked that story because it was important to me that it's not always best to do it all yourself. It would have taken me a lot longer, and I was extremely grateful for everyone on that volunteer team, and all the people that we were able to pull in that were happy to help because we were able to get [the student teams] up and running so much faster… On my own, I wouldn't have been nearly as effective and probably would have been much more flustered and angry, and not communicated as well. With the support of a whole team, we were able to handle the situation.*"

Similar to other participants, Susan highlighted collaboration as a core aspect of effective engineering work. For instance, by working together, the volunteer team was able to leverage their respective skill sets to get student teams up and running quickly. By comparison, Susan noted that trying to support student teams on her own would have been ineffective and likely would have made her feel frustrated and angry.

Susan selected "Engineering is a social discipline" as aligning less well with her engineering experiences. When justifying her selection, Susan described a curricular experience where she worked with three different teams over a single semester. Comparing across these three team experiences, Susan found that:

"*Among those three groups, it was interesting to watch how effective the team was as compared to how close the people on that team were. It actually turned out... these things carry across what I've seen in other classes as well, but the effectiveness of the team, you didn't actually have to know the other people very well, you really only needed to know their skills and be able to communicate with them effectively. You didn't need to know what they were doing in their personal lives and you didn't need to be their best friend...*"

Susan elaborated on this point by comparing the experiences of two teams in greater depth. One team, which Susan identified as her favorite, was described by Susan as "not close and very effective." She described her experience working on this team as follows:

"*We'd all split up into our little groups. We found it effective in that group to only focus on the tasks at hand. We communicated well and got along and it was a good time, but we didn't walk out of there with new best friends or anything like that. Instead of spending that time building social bonds, we were able to spend that time building almost like professional bonds or working bonds that we found were effective in solving problems, staying calm on competition day, and knowing who had what skills.*"

Susan enjoyed her experience on this team because her team members were focused on their group project and leveraged their respective skill sets effectively to develop a successful solution. Susan juxtaposed this experience with another team experience that she described as "close, but not effective:"

"*One of the people on the final project team, they just liked to know what you were up to and how your weekend was and, 'Oh, it would be really cool if …' like kind of bringing passions into our project. It's good to have passion for a project, but then it was really easy to get distracted on, 'Ah, it would be so cool if we painted it red or if we could grow 95 types of seeds in it,' or, 'These are all the things I would do,' and like, 'This is how we could draw it out because it would be fun,' and we would get really distracted. There's a whole bunch of fun things to talk about, but it would sidetrack us from the actual project and then we'd forget what we were doing and forget who was doing what. We'd kind of lose focus almost, and I walked out of there with great friends but not a great project. It was kind of a trade-off, like, 'Now I can talk to you all day about our project that didn't work.' There have been a couple teams where I walk out with both friends and a project, but most of the time if I have friends I will only have an okay project.*"

Susan felt that this project team was less effective because of their "social" interactions. While the experience was enjoyable from a personal standpoint, the team frequently became side-tracked by personal discussions and ultimately failed to develop a working product.

Thinking across her previous team experiences in general, Susan saw little connection between developing close relationships with teammates and achieving successful engineering outcomes. As she explained:

"*I have had teams that were composed of my friends and were not effective at all. I've had teams that were composed of friends that were effective, but I haven't seen any correlations between being close with the people around you and spending a lot of time on social activities and getting to know one another, and the actual outcome of your project. While there are aspects of engineering that are, not to say that being social isn't important to engineering, but I think you can get away without a lot of it. Out of the list of [statements] here, it's the one that I think you could, you could take 'social' out of engineering and be just fine, but I think the rest of the things on your list here you really do need in engineering. Because, all you need to be able to do is communicate effectively, but you don't need to know how everybody's kids are doing or if they* *went to the Bahamas. It's not as important to form those social bonds to create a good product as it is to understand your team's skills and how they like to communicate.*"

As such, Susan felt that the ability to communicate effectively with team members was a much greater predictor of engineering team success than personal feelings of closeness between team members. Susan identified several topics of discussion, such as family or vacations, that might be nice to know at a personal level but were ultimately irrelevant to engineering work. In that sense, Susan felt that the statement "Engineering is a social discipline," as she interpreted it, was negotiable as a descriptor of effective engineer work, especially compared to the other statements provided during her interview.

5. Discussion

5.1 Engineering students' conceptions of "social" in engineering contexts

As described in our background and methods, there are many ways that engineering qualifies as a social discipline. Engineering work broadly impacts society at both local and global levels, and these impacts affect both present and future generations. Engineers also collaborate with users and stakeholders, particularly in co-design contexts, and often work with other engineers to complete engineering tasks.

We provided participants with eight statements that reflected various technical and social aspects of engineering work. Our open-ended exploration of participants' engineering experiences using these eight statements revealed participants' implicit conceptions of what "social" does and does not refer to in the context of engineering. Our participants emphasized the role of teamwork in their previous engineering experiences and highlighted the importance of employing effective strategies for collaboration and communication. Ten participants also discussed how collaborations in engineering benefitted from the inclusion of diverse perspectives. This latter finding in particular aligns with observations made by Benedict et al. [53], who found that first-year engineering students similarly recognized the advantages of including diverse ways of thinking within engineering teams.

However, as explored in greater depth with the case of Susan, several participants differentiated collaboration and communication from other activities that they considered to be less important for engineering work, such as getting to know teammates personally or building friendships with peers. Participants often described these latter activities as being more "social" in nature. Based on this interpretation of "social," 15 out of 30 participants felt that the statement "Engineering is a social discipline" did not align well with their experiences.

Participants' discussions of the social aspects of engineering work mainly related to interactions between engineers. Few participants discussed beliefs related to engineering with stakeholders. Discussions of the social impacts of engineering work were also relatively limited. Participants indicated that engineering work should positively impact society when discussing the statement "Engineering makes the world a better place," but this statement was chosen infrequently overall (5/30 participants for "align," 9/30 participants for "not align"). Participants also generally touched on the importance of considering societal implications or stakeholder needs as part of their engineering work, but these discussions were not connected to any particular statement.

There are a few possible reasons why our participants may have interpreted the statement "Engineering is a social discipline" mainly in terms of interpersonal interactions rather than the social impacts of engineering work. For instance, participants may have felt that the social impacts of engineering work were sufficiently captured by the statement "Engineering makes the world a better place." Another explanation is that participants might not have readily associated "social" with "social impacts" due to limited engagement with the social impacts of engineering work in their previous education and internship experiences. Participants may also have interpreted "social" as referring to interpersonal interactions due to common uses of the word "social" in modern culture (e.g., "social" media). Furthermore, several common stereotypes (e.g., as compiled by Riley [54]) portray engineers as "antisocial" and/or socially awkward. These stereotypes of "antisocial" engineers may be very salient for engineering students; Litchfield and Javernick-Will [40], for instance, described engineering students spontaneously mentioning and subsequently rejecting these stereotypes when discussing their engineering identities. Thus, stereotypes of "antisocial" engineers may have influenced how participants in our study interpreted the word "social" as well.

There are also several potential explanations for why our participants seemed to view collaborating with teammates as a separate and distinct activity from befriending teammates (i.e., "social bonding"). The first potential explanation relates to how collaborative activities seemed to be framed in participants' coursework. Participants indicated that collaboration was often a core, explicit part of their engineering assignments. However, based on participants' accounts, it seems that engineering courses did not typically discuss the ways that informal, interpersonal interactions might affect engineering collaborations. As a result of these curricular experiences, our participants may have possessed relatively narrow understandings of collaboration as a core aspect of engineering work. In other words, our participants seemed to recognize the value of collaboration for completing technical tasks but may have possessed limited conceptions of how interpersonal dynamics might impact collaboration outcomes.

Our participants may also have differentiated collaboration from social bonding because they felt that "work" and "life" represented separate spheres of activity. For instance, several of our participants indicated that building friendships with peers was generally important; they just felt that socializing should occur in separate settings or at separate times from technical engineering work. Additionally, participants seemed to recognize the value of building professional relationships with teammates that were grounded in shared work experiences. Participants did not feel that personal bonding was necessary for such professional relationships to be successful. As described by Susan: "It's not as important to form those social bonds to create a good product as it is to understand your team's skills and how they like to communicate."

A third potential explanation is that our participants' differentiation of collaboration from social bonding may reflect a technical/social dualism in students' beliefs about working with other engineers. This explanation stems from the consistent emphasis that participants placed on the technical goals and contexts of their collaborations. As defined by Faulkner [55] based on a review of prior literature, the technical/social dualism refers to the tendency of engineers to prioritize technical knowledge as core to engineering work while devaluing interpersonal competencies. For example, engineers may view their ability to use tools as more important to their engineering work than their ability to manage other engineers. In the context of engineering educational environments, Tonso [56] has also described how “social” traits such as friendliness and an awareness of teammates’ personal interests may go unrecognized and uncelebrated compared to technical expertise. Faulkner [31], [55] and Tonso [56] have both noted that the technical/social dualism (i.e., valuing technical knowledge over interpersonal skills) frequently encompasses stereotyped gender norms (technical = masculine, social = feminine) and thus reinforces the centrality of maleness in engineering at the exclusion of women.

Regardless of the explanation, there are several reasons to be concerned that engineering students may perceive social bonding as separate from, and less important than, the technical aspects of collaboration. For example, due to this differentiation, engineering students may downplay or otherwise fail to recognize the contributions of teammates that they perceive as acting in more “social” (i.e., interpersonal, people-oriented) ways. This dynamic may contribute to the exclusion of women engineering students in particular, since work by Tonso [56] indicates that women students, regardless of their technical expertise, may be perceived by teammates as inhabiting more “social” team roles. Findings from Meadows and Sekaquaptewa [57] further suggest that women engineering students may even perceive their relegation to more “social” (i.e., people-oriented) team roles as voluntary, despite viewing such roles as less desirable than the more technical roles inhabited by male teammates. Cross and Paretti [58], in their study of African American male engineering students’ experiences in teams, also found that informal social interactions played an important role in enabling their participants to feel comfortable in mixed race teams. The devaluing of social interactions, particularly by White engineering students, could thus have adverse effects on minoritized students’ feelings of belonging in engineering.

Furthermore, it was not always clear how participants defined “building friendships” and “social bonding.” For instance, Susan described social bonding as the sharing of personal information that was irrelevant to engineering activities. However, several participants emphasized the value of including diverse perspectives within their collaborations, suggesting that there could be some types of personal information that may be relevant to engineering and thus okay to share. The ways that engineering students distinguish between relevant and irrelevant personal information has important implications for inclusion within engineering spaces. As one example, Smith and Lucena [32] found that low income, first generation engineering students possessed unique and important engineering competencies that they had developed through their personal experiences. It is unclear whether such students would be able to leverage, or would even mention, their experiential knowledge in cases where their peers considered the discussion of personal experiences to be outside the realm of legitimate engineering work.

Lastly, drawing clear distinctions between “social bonding” and collaboration may ultimately be counterproductive for professional engineering practice. Professional engineers often switch between a variety of technical and social roles throughout a typical workday [7], [8], [55], [59]. Hatmaker [59], in particular, in her study of professional engineering roles, demonstrated that building personal relationships with co-workers and clients is an important part of professional engineering work. Engineering students who believe that bonding with their collaborators is unnecessary may thus be losing opportunities to develop necessary interpersonal competencies prior to entering the workforce. Furthermore, these students may also consequently struggle to understand the value of other engineering practices that seem “non-technical” in nature, such as stakeholder engagement, but that are integral to effective engineering work.

5.2 Limitations

The open-ended nature of our interview protocol enabled participants to discuss their engineering experiences and their beliefs about engineering work in depth. However, our interview questions did not explicitly ask participants to share their beliefs; rather, this information emerged naturally as participants described and interpreted their prior experiences. As such, participants may have possessed beliefs about engineering work that were relevant to this study but that did not emerge during interviews.

Participants also did not consistently interpret our eight statements about engineering work (Table 2) as intended. In particular, we originally meant for "Engineering is a social discipline" to capture, at least in part, the broader societal implications of engineering work. However, most participants interpreted this statement in terms of interpersonal interactions instead. Since we did not define our eight statements for participants, it is unclear if participants' interpretations of "Engineering is a social discipline" reflected participants' narrow understanding of the social aspects of engineering work or rather a lack of clarity in the statement itself.

A third limitation was the relative lack of racial diversity across our participant sample, with 60% of participants reporting White as their racial identity. Engineering students with other racial identities would likely discuss different beliefs about engineering work.

Furthermore, our research team was composed of three White women and two White men who possessed a range of experience levels from undergraduate engineering student to tenured faculty member. Shared identities between our research team and many of our participants facilitated our data collection and data analysis processes. However, we also recognize that there are several potential ways to interpret our data, and the points that we highlight in our discussion section are in part informed by our personal perspectives. A different set of researchers (and particularly researchers of color) might draw different insights from our data and/or frame their findings in a different way. It is also possible that a more racially diverse research team would have elicited different interview responses from the same sample of participants.

Lastly, it is possible that our sample of participants may have been particularly social or outgoing compared to their peers. Our study solicited participants through emails to department listservs, meaning that our participants were all volunteers. It is unclear whether less outgoing engineering students would be interested in volunteering as study participants. This potential over-weighting towards outgoing engineering students could explain why many of our participants chose "Engineering is a team discipline" as aligning with their engineering experiences.

5.3 Implications

Engineering instructors can use our findings to support engineering students in developing more holistic views of engineering as a social discipline. For instance, relatively few participants discussed the societal impacts of engineering work in depth. In part, this finding may have emerged due to a gap in students' understandings about the social aspects of engineering work. However, this finding may also reflect a gap in students' engineering education, since few participants described curricular or work experiences where the societal impacts of engineering work were evident. As such, engineering instructors might support students in developing deeper conceptions of engineering as a social discipline by centering the societal impacts of engineering work in their curricula. For instance, instructors might reframe homework problems to reflect the societal contexts of engineering work (e.g., as described in [60]). Depending on the course topic, instructors might also introduce content related to social context assessments. However, given the traditional technocentric focus of engineering educational culture, instructors should be prepared to navigate potential pushback from students that may occur in response to centering the societal impacts of engineering work in their curricula.

Engineering instructors might also use our findings to restructure team- or group-based assignments for their courses. Recommended practices for team formation have been described extensively by previous studies. For example, instructors should sort students into heterogeneous teams that include diverse perspectives [61]. Instructors should also try to balance the gender or racial composition of their teams as much as possible [57], [58], [62]. However, our findings suggest that even if engineering instructors follow recommended practices for team formation, some engineering students (particularly White students, given the demographics of our participant sample) might still inadvertently adopt exclusionary behaviors within their teams due to personal beliefs about what “productive” collaboration does and does not entail.

Engineering instructors may be unaware that exclusionary team interactions are occurring since instructors are often responsible for monitoring many teams simultaneously and the majority of team work for courses such as capstone may occur “outside” of the classroom. However, since the beliefs described by our participants were strongly influenced by their curricular and work experiences, our findings point to ways that instructors might adjust curricular environments to reduce the likelihood of exclusionary team behaviors. For instance, instructors might reduce the amount of work required to complete their projects so that students feel less inclined to adopt a “divide and conquer” approach that minimizes interactions between team members. Instructors might also introduce content into their curricula that highlights the interpersonal dimensions of professional engineering practice and supports students in developing skills for effective and inclusive collaboration. Instructors might further reduce the likelihood of exclusionary team behaviors by implementing inclusive teaching practices, such as openly acknowledging and valuing the contributions of diverse students and fostering a sense of community in their courses.

Based on our findings, instructors might also conclude that they should incorporate “social” criteria for their team projects that incentivize teammates to get to know one another personally. On the surface, this approach seems like it might address the potential distinctions that (particularly White) engineering students may draw between the “technical” and “social” aspects of collaboration. However, we would caution *against* such an approach, at least without significant forethought, because it potentially ignores the specific barriers that minoritized students often encounter in engineering educational contexts and might even create additional barriers to participation for students who may struggle to engage with their peers due to their identities. Ultimately, as suggested by Faulkner [31], [55], Tonso [56], Riley [54], and others, the tendency of some engineers to downplay the interpersonal aspects of their engineering work is as much a reflection of engineering culture as it is an individual characteristic. Long-term, equitable solutions thus require cultural change beyond simply individual change.

6. Conclusions

Our study explored the beliefs that junior- and senior-level engineering students possessed about the social aspects of engineering work based on their previous education and work experiences. We provided participants with eight statements related to the technical and social aspects of engineering work and asked them to select two statements that aligned with their experiences and two statements that did not align well. Most (17 out of 30) participants selected "Engineering is a team discipline" as a statement that aligned closely with their previous experiences and, during discussions of this statement, highlighted the importance of communication and collaboration for effective engineering work. However, 15 out of 30 participants selected "Engineering is a social discipline" as a statement that aligned less well with their experiences; participants often justified their choice by describing how "social" activities, such as befriending teammates, are separate from and unnecessary for effective collaboration. Our findings thus seem to indicate a potential technical/social dualism in how engineering students may perceive their collaborations with other engineers. Our findings also suggest that some engineering students may hold narrow conceptions of the social aspects of engineering work, since discussions related to collaborating with users or communities and/or evaluating the social impacts of engineering work were relatively limited across our participant sample. By highlighting specific gaps in the ways that engineering students may conceptualize the social aspects of engineering work based on their previous experiences, our findings can support engineering instructors in adjusting their engineering curricula to promote more holistic and inclusive views of engineering.

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