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”I struggled with how to meaningfully factor ethics into a project optimizing missiles:” An analysis of first-year engineering students' engagement with sociotechnical thinking

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Abstract

Engineering is inherently sociotechnical, yet students often enter undergraduate engineering programs with limited frameworks for understanding how social, ethical, and contextual factors influence engineering practice, or for how their engineering practice shapes society. This study examines how first-year engineering students engage with sociotechnical thinking within an introductory, project-based design course that intentionally integrates sociotechnical reflection throughout the design process. Specifically, we investigate how students perceive and value sociotechnical dimensions of engineering and how they incorporate these considerations into their design work.

We draw on data collected from first-year engineering students enrolled in a two-semester introductory engineering course sequence. Quantitative data include pre- and post-course Likert-scale surveys assessing students' valuation of technical communication, teamwork, ethics, social impacts, and related sociotechnical skills. Qualitative data consist of over 200 written reflections responding to structured prompts that foreground sociotechnical dimensions of students' semester-long design projects. Qualitative analysis employed a combination of deductive and inductive coding; quantitative trends were analyzed using nonparametric statistical tests.

Results indicate that students entered the course valuing technical communication, ethics, and social impacts, with significant post-course gains in perceived skill and valuation of communication and social impact. However, reflections revealed that many students struggled to translate sociotechnical awareness into future career considerations, often prioritizing technical experiences, financial security, or prestige over societal considerations. Together, these findings reveal a generative tension: first-year students have capacity for engaging in sociotechnical thinking but lack experience and operational frameworks to integrate it into engineering practice. Structured reflection prompts and intentional course design may help catalyze early engagement, positioning sociotechnical thinking as foundational rather than peripheral to engineering.

Introduction

Engineering educators must prepare students to consider the sociotechnical dimensions of their work. Equipping students to engage in sociotechnical thinking, which involves integrating societal, ethical, and contextual factors into engineering problem-solving, is one approach to achieving this goal. Introductory engineering courses often serve as students' first exposure to engineering design processes and professional values, making them an important point for introducing sociotechnical thinking.

In this study, we explore how first-year engineering students engage with sociotechnical thinking in an introductory engineering course. The purpose of this study is to understand the extent to which first year engineering students identify and incorporate sociotechnical dimensions in their design work. By examining these early experiences, this research provides insight into how introductory engineering courses may help students perceive sociotechnical thinking as part of engineering practice and critiques ways these efforts may fall short in fostering deep and sustained engagement with sociotechnical thinking.

Background

Engineering education has been characterized by a "culture of disengagement," a tendency to separate technical work from its innate social and ethical dimensions [1]. This cultural orientation promotes the belief that engineering is objective and apolitical, discouraging engagement with questions of justice, equity, and responsibility. Such disengagement is reinforced by broader cultural phenomena that frame engineering as a purely technical endeavor, marginalizing sociotechnical dimensions in professional identity formation [2].

The lack of sustained integration of sociotechnical thinking in engineering curricula is particularly concerning given its importance in professional engineering practice. More than ever, employers seek graduates who can navigate complex sociotechnical systems, communicate across disciplines, and anticipate the broader implications of their work [3], [4]. Industry reports consistently emphasize the need for engineers who possess not only technical expertise but also ethical reasoning, stakeholder awareness, and contextual sensitivity [5], [6]. These skills are essential for addressing challenges such as sustainability, equity, and public trust in technology. Recent labor-market trends, including shifts in employment outcomes across fields of study, further underscore the need for adaptable engineers who can engage in sociotechnical thinking [7], [8].

While sociotechnical thinking has several broad definitions, in this study we define sociotechnical thinking as the capacity to recognize, analyze, and integrate both technical and social dimensions in engineering problem-solving. Drawing on frameworks from sociotechnical thinking and Science, Technology, and Society (STS), this work understands engineering not as an objective or purely technical endeavor, but as a socially situated practice shaped by broader societal contexts and values. Sociotechnical thinking emphasizes the integration of technical and social considerations in engineering decision-making, while STS highlights the importance of critically examining the societal implications of technological development [9]. Central to both perspectives is the recognition that engineering impacts society, and society in turn influences engineering through cultural norms, institutional practices, and stakeholder expectations. Internal reflection on assumptions, biases, and professional norms is therefore essential for meaningful engagement with diverse perspectives and actors. While first-year students can only begin to engage with facets of this complex concept, early exposure is critical for developing enduring habits of sociotechnical thinking.

Although ABET accreditation standards include outcomes related to societal impact and ethics, these components are often treated as peripheral and inconsistently implemented [9]. Core engineering courses rarely integrate sociotechnical dimensions, and when present, sociotechnical thinking is frequently siloed into standalone ethics or communication courses [2]. This compartmentalization incorrectly signals to students that sociotechnical dimensions are secondary to technical problem-solving and not central to engineering practice. Recent research confirms that curricular structures and pedagogical norms perpetuate a technical-social dualism and limit opportunities for students to engage deeply with sociotechnical thinking [10].

As a result of the compartmentalization of sociotechnical dimensions in engineering education, students often internalize these priorities, developing a limited appreciation for the relevance of sociotechnical thinking in their professional formation. Studies show that engineering students frequently view social and ethical issues as subordinate to technical issues, what they perceive as the "real" work of engineering [1]. Pedagogical approaches that emphasize efficiency and correctness over critical reflection further reinforce this perception [11]. When students encounter sociotechnical thinking, their engagement tends to lack depth; while they may acknowledge societal context in theory, they often fail to integrate sociotechnical dimensions meaningfully into design processes [12]. Further research highlights that without sustained exposure to sociotechnical dimensions of engineering, students struggle to recognize the value of these perspectives in addressing complex, real-world problems [13].

Despite growing recognition of the need for engineers who can effectively engage in sociotechnical thinking, prior literature reveals a lack of pedagogical strategies for deeply embedding sociotechnical thinking into first-year engineering curricula. Existing efforts often remain superficial or isolated, failing to cultivate the habits of mind necessary for sustained engagement with sociotechnical thinking [13], [14]. Addressing this gap is essential for preparing engineers who are equipped to navigate the ethical, cultural, and political dimensions of their engineering work.

Research Questions

In this study, we begin to explore ways in which first-year engineering students engage in sociotechnical thinking in an introductory engineering course sequence that purposefully introduced and integrated sociotechnical thinking habits into engineering design. The purpose of this study is to understand the extent to which first-year engineering students identify and incorporate sociotechnical thinking into their design work, and to provide insights into how introductory engineering courses might better prepare students to perceive and appreciate sociotechnical dimensions of engineering practice. To accomplish this, our work addresses the following research questions:

RQ1: How do first-year engineering students perceive and value sociotechnical dimensions of engineering practice after completing an introductory design course, if at all?
RQ2: In what ways, if at all, do first-year engineering students demonstrate engagement with sociotechnical thinking, and what challenges do they encounter when engaging in sociotechnical thinking?

Methods

In this study, we employed a concurrent mixed-methods approach to examine first-year engineering students' perceptions and valuation of sociotechnical dimensions of engineering. Qualitative written-reflection data provided a nuanced understanding of the quality and depth of participants' engagement in sociotechnical thinking, while quantitative survey data provided information about general trends in participants' perceptions of sociotechnical dimensions to affirm patterns observed qualitatively. Thus, we collected and analyzed both quantitative survey data and qualitative written-reflection data from consenting first year engineering students, as described in the following.

Context

This research was conducted at a mid-sized, public research university located in the Mid-Atlantic region of the United States. The engineering school enrolls approximately 3,000 undergraduate engineering students across multiple disciplines. All first-time, first-year engineering students are required to take a year-long introductory engineering course sequence. These two, sequential introductory engineering courses are designed to provide first-year engineering students with foundational skills in engineering design, teamwork, and problem-solving through project-based experiences and have purposefully introduced and integrated sociotechnical thinking habits into engineering design. These courses serve as a gateway to the engineering profession and aim to prepare students for subsequent coursework while introducing them to broader professional values.

The second-semester course builds on the foundations established in the first course and provides students with their first opportunity to select a project aligned with their interests. Students are grouped into teams based on their preferred project, selected from a curated list representing challenges across diverse engineering disciplines. Each team is assigned a real client and tasked with designing and building a product from scratch to meet the client's needs over the course of the semester. This project-based structure emphasizes authentic design experiences, requiring students to engage in sociotechnical thinking as they balance technical feasibility with stakeholder requirements and broader contextual considerations.

At the start of the first semester and again at the end of the second semester, students in the course took a survey which, among other things, assessed students' perceptions of sociotechnical dimensions in engineering practice. Quantitative data used in this study is made of pre-post survey responses to the following survey questions (Table 1):

Table 1. Quantitative Survey Items and Likert Scale Responses

Question Text	Items	Likert Scale
Do you personally value…?	Technical Communication Thinking about Ethics Considering Social Impacts	1= no, not at all 5= yes, very much
Do you consider yourself skilled at…?	Technical Communication Thinking about Ethics Considering Social Impacts	1= no, not at all 5= yes, very much
Please rate your agreement to the statements:	I receive guidance & tools for collaboration in my engineering courses. Engineers need to collaborate in teams when solving problems. I feel I have a set of tools/skills that will help me be a more effective teammate. I am satisfied with my experiences working in teams in engineering. It is important to me to learn how to work in teams with other students.	1= strongly disagree 5= strongly agree
Describe your confidence in your ability to design a product or process in a team.		1= terrible 5= excellent

To scaffold sociotechnical engagement throughout the course, students were regularly asked to write reflective paragraphs on a set of Challenge Essential Questions (CEQs), structured reflection prompts designed to help students critically examine the sociotechnical dimensions of their projects. The CEQs were adapted from and informed by prior work demonstrating how such questions can be used to explicitly connect technical, social, and ethical content in first-year engineering curricula [15]. CEQs were introduced as a pedagogical intervention to counter students' tendencies to treat sociotechnical considerations as secondary or separate from technical design work by repeatedly foregrounding these dimensions throughout the design process.

CEQs prompted students to consider stakeholder needs, ethical implications, sustainability outcomes, and societal impacts alongside technical feasibility when making design decisions. Students responded to the CEQs in written reflections three or more times each semester, allowing them to revisit and apply sociotechnical perspectives across multiple design contexts. In this study, the qualitative written reflection data is students' final written responses to the CEQs at the end of their second semester. The full set of CEQs is listed below:

Challenge Essential Questions (CEQs):

- Problem framework: Who are the primary technical, social, natural, conceptual, and economic actors and how did they affect your process?
- Sustainability: How did you address economic, societal, and/or environmental sustainability challenges in the design process and any potential tradeoffs?
- Universal Design: How did you incorporate the principles of Universal Design through the process?
- Ethics: What are the ethical considerations and implications that you considered when generating a solution?
- Teamwork: How did you work effectively as a team member, and what tools did you use to help your team be productive?
- Communication: How did you effectively document and communicate the merits of your design and process to relevant stakeholders?

Participants and Data Collection

All students enrolled in the two-semester introductory engineering course sequence were assigned the written reflection assignment and pre-post-surveys as part of the course. Of the total first-year population, 304 students consented to allow their written reflection assignments to be included in this study, and 451 students consented to allow their survey responses to be included. This study was reviewed and approved by the institutional review board.

Analysis

We analyzed qualitative data using thematic coding informed by prior literature on sociotechnical thinking [9], [12]. Codes captured evidence of stakeholder consideration, ethical reasoning, societal impact, and integration of contextual factors into design decisions (Table 2). The first author created the codebook, and two additional researchers independently coded a subset of 20 artifacts to establish inter-rater reliability. The research team discussed agreements and disagreements across all code applications in order to reach a shared understanding of the codebook and refine code definitions. The first author then coded the full dataset using the finalized codebook (Table 2).

We synthesized codes by examining recurring patterns and relationships across reflections, with particular attention to how sociotechnical considerations were articulated alongside technical decision-making. As inter-rater reliability efforts expanded and additional reflections were analyzed, recurring themes became more apparent, prompting iterative refinement of the codebook, including the addition or clarification of codes and recoding of previously analyzed artifacts to ensure alignment with emergent findings.

Table 2. Final qualitative codes and their definitions

Code	Definition
Decision making process	Reflection on the process of making a decision instead of just reporting on the result of their decisions
Implementation of Design	Consideration for a greater community of individuals or how your design is part of a network
Ethics	Deeply considering ethical implications of a design
Resistance	Evidence of students rejecting, resisting, recoiling from sociotechnical thinking
Safety	Demonstrating consideration for the safe implementation of the product design
Social Responsibility	Reflecting on engineers' obligation and responsibility to society
Sustainability	Deeply considering sustainable implications of a design
Economic prestige	Motivated by a desire to obtain a high paying job, title, status
Social Prestige	Motivated by a desire for virtue and social contribution
Future Thinking	Appreciating the value of STS skills for the future, including working with others
Enthusiasm	Evidence of students embracing, enjoying, etc. sociotechnical thinking
Influences	The forces that students cite as influencing their design decisions (e.g., budget, material, client, size, laws, ability, etc.)
Perspective	Demonstrating respect for other ideas (related to sociotechnical thinking)
Prioritize	Recognizing that there is not one right/true/best idea and they get to choose to prioritize some things over others
STS Communication	Recognizing that engineering is more than computation, recognizing the value of communication and collaboration

Quantitative survey data were analyzed to identify pre-post changes in students' self-reported perceptions of sociotechnical dimensions of engineering. We assumed that Likert scale survey responses had equal intervals to allow comparisons and statistical testing. Anderson-Darling tests indicated non-normal distributions; therefore, we used Mann-Whitney nonparametric tests to assess significant differences between pre- and post-course scores.

To strengthen the validity of our findings, we triangulated results from across three sources: pre-post survey data, students' written reflections in response to the CEQs, and course context documentation (e.g., syllabus, daily slides, and other course content). Survey data provided broad trends in students' valuation and perceived skills, while reflections offered nuanced insights into how students articulated sociotechnical thinking in practice. Course context documentation provided important information about the experiences that students were having at different points in the semester. Triangulation allowed us to identify convergences and divergences amongst the data sources, enhancing the robustness of our conclusions.

Limitations

Data in this study comes from a single institutional context and single course sequence. Additionally, sociotechnical thinking is a complex construct, and first-year students may only demonstrate partial engagement with its dimensions. Data relied on artifacts and self-reports, which may not fully capture students' reasoning processes. Participation was voluntary, introducing potential self-selection bias toward students who were more engaged, held stronger opinions about the course, or more comfortable sharing their work, which may not represent the full population. Furthermore, across all sections of the course, the reflection assignments that incorporated CEQs varied slightly in format and timing, even though the CEQs themselves were consistent. This variability in assignment structure meant that student responses were not standardized across sections, which may have influenced the consistency of the data.

Positionality

The first author drove much of the thinking and analysis in this study and has reflected on their positionality. They acknowledge their position as an engineering student and a woman in engineering, coming from an academically privileged background with prior exposure to social issues and ethical reasoning. These experiences mean that concepts such as sustainability and sociotechnical thinking were not entirely new to them when taking the introductory engineering course analyzed in this study. They also recognize that their interest in humanities and enjoyment of reading and writing leads them to highly value the reflective and communication-based components of the course. These factors positioned the first author to approach integration of sociotechnical thinking with a lens informed by prior familiarity and personal engagement with professional skills. All authors share a similar recognition of the essential nature of sociotechnical thinking to success in engineering. Furthermore, all authors on the team are deeply involved in the course from which data was collected. Two authors are instructors for the course, two authors are teaching assistants for the course, and all undergraduate authors are former students of the course. This deep involvement and investment in the success of the course may shape interpretation of findings.

To mitigate potential bias, coding procedures involved collaboration with multiple researchers and iterative discussions to ensure interpretations were grounded in evidence rather than assumptions. The authors reflexivity throughout the study by documenting analytic decisions and considering how their backgrounds and values align with the goals of sociotechnical integration.

Findings

Participant Valuation of Technical Communication, Ethics, and Social Impacts

Participants reported that they valued technical communication, ethics, and social impacts both before and after the course, with average scores greater than 4 out of 5 on items such as "Do you personally value technical communication?" (Table 3). High pre-course scores indicate that participants entered the course with an appreciation for technical communication, ethics, and social impacts (aspects of sociotechnical thinking) and were not entirely unfamiliar with their importance in engineering.

Table 3. Quantitative Mann-Whitney test results for pre post comparison of participants' valuation and skills

Question Text		Pre		Post		Mann-Whitney	
		Mean	STD	Mean	STD	Statistic	p value
Do you personally value	Technical Communication	4.44	0.70	4.64	0.58	62352.00	**0.000**
	Thinking about Ethics	4.20	0.86	4.30	0.86	68510.50	0.064
	Considering Social Impacts	4.32	0.80	4.46	0.75	66142.50	**0.006**
Do you consider yourself skilled at	Technical Communication	3.60	0.93	4.15	0.74	49106.00	**0.000**
	Thinking about Ethics	3.60	0.90	4.00	0.76	55259.50	**0.000**
	Considering Social Impacts	3.63	0.89	4.08	0.76	52118.50	**0.000**

Note: Bolded p values are significant at an $\alpha = 0.05$ level.

Mann-Whitney nonparametric tests revealed significant increases in participant's reported valuing of technical communication and considering social impacts from pre to post ($p < 0.01$; Table 3; Figure 1). Participants also reported being significantly more skilled in technical communication, ethics, and considering social impacts in the post-course survey as compared to the pre. ($p < 0.01$; Table 3; Figure 1). High pre-course scores alongside the significant increases in reported value and skill demonstrate that participants may have had some initial notions about sociotechnical thinking that were strengthened through the course. The dual effect of affirming pre-existing awareness of sociotechnical dimensions while deepening and operationalizing sociotechnical thinking, demonstrates that introductory engineering courses have potential to both introduce sociotechnical thinking to novices and enrich the understanding of students who already value these dimensions.

Figure 1. Quantitative pre post comparison of participants' valuation and skills

The qualitative data provide a more nuanced understanding of participants' views on sociotechnical thinking. Reflections reveal that for some participants, this introductory engineering course was their first meaningful exposure to sociotechnical thinking. Participant 238, a male student in biomedical engineering, explained:

> Sociotechnical thinking was hard to grow because I've never really had to do it before. Figuring out the sociotechnical factors impacting my project required me to critically think in different ways.

This sentiment was echoed by others who described sociotechnical thinking as unfamiliar and challenging. For example, Participant 326 reflected on the difficulty of integrating ethics into a defense-related project: "I struggled with how to meaningfully factor in ethics into a project optimizing missiles." The quantitative gains (Table 3) indicate that participants reported greater value for considering social impacts after the course, while the qualitative reflections illustrate a clear pattern of participants struggling to operationalize these ideas within design decisions. These findings together suggest that even if they do not yet fully understand how to operationalize sociotechnical thinking in their engineering practice, being challenged to regularly engage in sociotechnical thinking throughout the introductory engineering course sequence may have increased their value for understanding sociotechnical thinking.

Challenges in Meaningfully Engaging in Sociotechnical Thinking

Ethical aspects of sociotechnical thinking remained particularly disconnected from participants' everyday engagement with the course. Quantitative data reveal that participants reported lower valuation for thinking about ethics than technical communication or considering social impacts in both pre- and post-, and there was no significant increase from pre to post (Figure 1; Table 3). Qualitative data provide insight into this challenge. Participant 401 expressed:

> While we did reflect on ethics and sustainability, I sometimes found it hard to balance technical feasibility with broader societal impacts, especially when tradeoffs weren't clear.

Others echoed similar struggles, noting that ethical considerations felt secondary or abstract compared to technical requirements. Participant 312 wrote, "I understood why ethics mattered, but it felt disconnected from the actual design steps we were taking." These reflections suggest that while participants broadly reported that they valued ethics, with average scores greater than 4 out of 5 both pre and post, they require additional support to connect these aspirations to the daily practice of engineering. The CEQs may have challenged participants to think about ethics and integrate such thinking into their designs, but they may still struggle to do so meaningfully.

Further, many participants framed their future engineering careers around economic or prestige-based outcomes rather than civic responsibility, demonstrating limited appreciation for engineering's social dimensions. Participant 339 captured this sentiment succinctly, saying "I still really didn't know what engineering was except for the fact that I loved math and physics, and I wanted to make money." Similarly, Participant 326 reflected on career decisions in terms of income and prestige, "In the end, it will come down to how much I value the higher pay of medicine vs. the temporarily delayed high income from airline flying, compared to the enjoyment and prestige of my work." These reflections reveal a limited recognition of social or political agency, even when participants anticipate working in sectors with pronounced ethical implications such as medicine. In contrast, few participants did choose to frame their reflection on future goals through a lens of civic responsibility. For example, participant 329 said, "to me, this was what being an engineer was all about - creating something with real world impact." Echoing this orientation toward real-world consequences, Participant 403 described how engaging with authentic client needs sharpened their sense of responsibility and motivation,

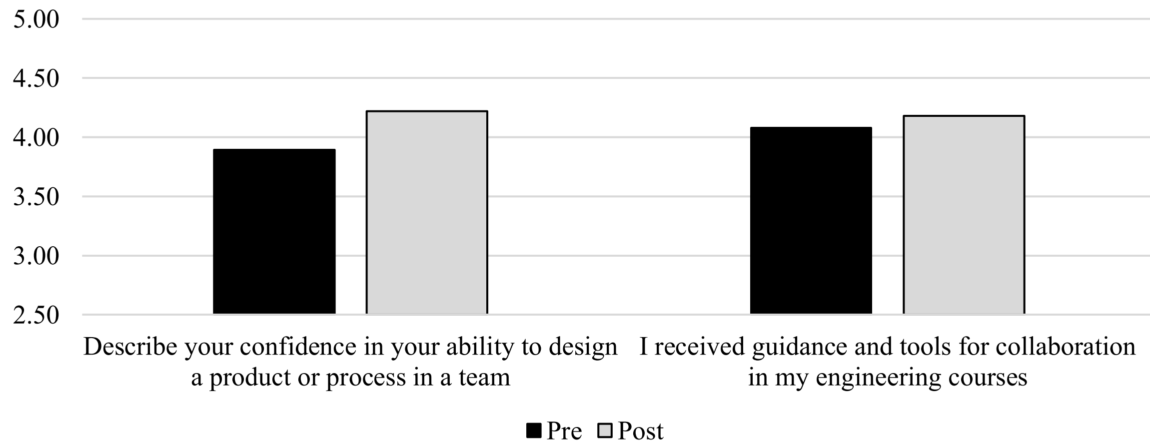
> I feel much more motivated and fulfilled during projects that I feel will have a real impact, and this course was the epitome of that. Every decision felt like it mattered more because we had a client depending on it, and I feel our project really benefited from it.

While discussion of social or political agency was infrequent, its appearance in our data demonstrates the potential capacity of first-year engineering students to consider social outcomes of engineering, further underscoring the need for explicit curricular efforts to frame engineering as a sociotechnical profession with sociotechnical implications to all engineering work.

Valuation of Teamwork as Compared to Sociotechnical Thinking

Although quantitative data shows significant gains in participants' valuation of teamwork and sociotechnical thinking, qualitative data demonstrate different depth of engagement with these concepts. Survey data showed significant growth from pre- to post-survey in participants' reported confidence in their ability to design a product or process in a team, and an increase in the perception that they received guidance and collaboration tools (Figure 2; Table 4).

Figure 2. Quantitative pre post comparison of participants' valuation and skills



Qualitative reflections reinforced these patterns, as participants consistently highlighted teamwork as an essential and rewarding part of their engineering practice. For example, Participant 342 wrote:

> One thing I liked about working with teams was being exposed to many different ideas, people, and communication styles. Hearing multiple solution ideas from many perspectives was very beneficial, widened my ideas, and allowed the team to combine multiple ideas to develop the best solution.

Participants not only enjoyed working with their teammates, but their reflections reveal that they understand the benefits of collaborating for engineering practice. For example, collaboration led to the generation of more diverse ideas. For example, Participant 407, wrote:

> I liked coming up with ideas together and working together to get through any setbacks. I found my group fun to work with most of the time and I liked seeing everyone's unique perspectives on the problem because it made me think of things in ways I might not have otherwise.

These reflections align with quantitative findings showing high pre- and post-course valuation of teamwork (means greater than 4 out of 5; Table 4) and significant growth in reported confidence in the ability to design a process or product in a team ($p<0.001$; Table 4). These findings highlight participants' acceptance of collaboration as essential to engineering practice.

Table 4. Quantitative Mann-Whitney test results for pre post comparison of participants' views on teamwork

Question		Pre		Post		Mann-Whitney	
		Mean	**STD**	**Mean**	**STD**	**Statistic**	**p value**
Describe your confidence in your ability to design a product or process in a team		3.90	0.77	4.22	0.67	54057.5	**0.000**
Please rate your agreement to the statements	I receive guidance and tools for collaboration in my engineering courses	4.08	0.71	4.18	0.71	65650.0	**0.030**
	Engineers need to collaborate in teams when solving problems	4.61	0.58	4.56	0.61	74510.0	0.225
	I feel I have a set of tools/skills that will help me be a more effective teammate	4.16	0.67	4.24	0.70	66154.5	0.066
	I am satisfied with my experiences working in teams in engineering	4.04	0.77	4.01	0.89	71367.5	0.979
	It is important to me to learn how to work in teams with other students	4.50	0.58	4.49	0.60	71098.0	0.990

Note: Bolded p values are significant at an $\alpha = 0.05$ level.

In contrast to the depth of reflections on collaboration, fewer reflections revealed deep engagement with sociotechnical thinking. When sociotechnical dimensions were mentioned, they often appeared as secondary or disconnected from technical tasks. For instance, when prompted "What are the ethical considerations and implications that you considered when generating a solution?" Participant 408 responded, "Thought about driver/road safety." This demonstrates that they knew the type of response to give but did not think deeply or engage meaningfully in sociotechnical thinking when responding to this prompt.

In another example, Participant 371 said, "while sociotechnical thinking was the focus of many assignments, I never really understood it well. I had lots of trouble coming up without how sociotechnical factors connect to the engineering design process." These quotes provide evidence of students' struggle to reflect deeply on sociotechnical concepts and meaningfully connect such topics to engineering design, even when prompted to consider these concepts. This contrasts with the depth of reflection on teamwork, suggesting that while teamwork was treated as a necessary and essential aspect of engineering, sociotechnical dimensions were often perceived as optional or less essential.

Importantly, a small number of participants did begin to demonstrate depth in their sociotechnical thinking by explicitly integrating ethical considerations, stakeholder perspectives, and communication practices into their understanding of engineering work. For example, when reflecting on sociotechnical and ethical implications of their future careers, Participant 333 described the importance of considering multiple stakeholder perspectives and avoiding harm, noting that, "engineering as a field can solve many problems, but to make the idea work, you have to consider the problem from everyone's perspective and not harm one to lift another up." This reflection connects ethical responsibility with concern for society. There may exist an emerging recognition that engineering decisions are embedded within social relationships and have real consequences for others, and the existence of these few deeper examples demonstrates that first-year engineering students are capable of engaging meaningfully with sociotechnical thinking when supported by authentic design contexts and explicit reflection prompts, even though this level of depth was not yet common across the cohort.

Synthesis

RQ1: How do first-year engineering students perceive and value sociotechnical dimensions of engineering practice after completing an introductory design course?

Participants entered the course with an appreciation for technical communication, thinking about ethics, and considering social impacts. Post-course, valuation increased for technical communication and considering social impacts and participants reported greater skill in technical communication, thinking about ethics, and considering social impact. These gains suggest that introductory courses may bolster existing perceptions of the value of sociotechnical dimensions of engineering. However, qualitative reflections indicated limited depth and appreciation of sociotechnical thinking as central to engineering. Participants often viewed sociotechnical thinking as novel, challenging, or secondary. Overall, participants valued sociotechnical dimensions more after the course but did not yet consistently treat them as intrinsic to engineering practice.

RQ2: In what ways do students demonstrate engagement with sociotechnical thinking in their design work and reflections, and what challenges do they encounter in integrating these considerations?

Engagement in sociotechnical thinking was visible when participants were explicitly prompted to consider ethics, stakeholders, and social impacts; Yet participants frequently described difficulty balancing technical feasibility with broader societal implications, particularly under uncertainty or when trade-offs were ambiguous. Sociotechnical dimensions often appeared as post hoc reflections rather than formative constraints guiding design decisions. This pattern indicates both emergent engagement and integration challenges. Students may need concrete methods to move from acknowledgement of sociotechnical concepts towards operationalizing these concepts within engineering design practice.

Discussion

Embedding sociotechnical thinking in first-year curricula has several implications. First, it supports the development of professional and communication skills by encouraging students to articulate design decisions in relation to societal needs. Second, it counters the tendency reinforced by traditional engineering culture to treat social factors as secondary to technical problem-solving. Finally, it builds accountability for both technical rigor and social responsibility, preparing students to navigate complex challenges such as sustainability, equity, and public trust in their future careers.

Our findings illustrate a generative tension between first-year students' openness to sociotechnical thinking and their lack of frameworks and prior exposure, which underscores the need for intentional scaffolding. Although participants showed an openness to sociotechnical thinking, engagement often lacked depth. This finding is consistent with prior research on student discourse and motivation, which suggests that sociotechnical thinking requires intentional scaffolding and curricular support [9], [12]. Our findings further support prior work concluding that structured reflection and curricular design are essential for developing competency in sociotechnical thinking.

Participants valued sociotechnical dimensions and recognized their importance, as demonstrated by the survey data, but struggled to operationalize these ideas within design decisions and reflections. Findings suggest that structured reflection questions, such as the Challenge Essential Questions (CEQs), and course designs that foreground sociotechnical dimensions can help first-year engineering students begin to engage meaningfully with sociotechnical thinking, even if students have not yet internalized sociotechnical thinking as an essential part of engineering, and suggest that the sociotechnical integration in this course could be improved to further support students to work towards internalization. When prompted to consider stakeholder needs, ethical implications, and societal impact, participants began to recognize that engineering decisions are not isolated from cultural and contextual influences. These early experiences are critical for shaping students' understanding of engineering as a socially situated practice.

Our findings reveal a dual effect of engaging first-year students in sociotechnical thinking by both introducing sociotechnical thinking to students while simultaneously affirming pre-existing awareness of sociotechnical dimensions and helping students deepen their understanding and ability to operationalize these skills. This dual effect demonstrates that introductory engineering courses can both introduce sociotechnical thinking to novices and enrich the understanding of students who are already exposed to these skills. Designing courses with this flexibility is essential. If the approach were so narrow that only students with no prior knowledge could benefit, its impact would be limited, as many students enter their first year with at least some understanding and appreciation of sociotechnical dimensions of engineering. Both approaches are critical for normalizing sociotechnical thinking as a core element of engineering practice.

When compared to reflections on valuing teamwork, participants' engagement with sociotechnical thinking remained underdeveloped. Participants frequently struggled to connect technical feasibility with broader social impacts and often framed career motivations around financial or prestige-based goals rather than civic responsibility. These patterns reflect a broader tendency in engineering education to separate technical and social dimensions, which can hinder students' ability to see engineering as a socially embedded practice [1], [2]. While participants valued the idea of making a difference, they benefited from structured frameworks, such as those presented in the CEQs, to connect these aspirations to the daily practice of engineering. Without such scaffolding, students' motivations risk being overshadowed by professional norms that prioritize technical mastery or financial success. The devaluing of sociotechnical thinking underscores the need for explicit curricular strategies, such as embedding these considerations into reflection prompts, design projects, and assessment rubrics, to position engagement in sociotechnical thinking as a core competency rather than an add-on. Doing so will help shift student perceptions and establish sociotechnical thinking as an essential element of the engineering profession.

Intentional curricular strategies that integrate sociotechnical thinking into foundational courses, rather than relegating these considerations to peripheral or standalone modules, can help normalize engagement in sociotechnical thinking as a core component of engineering practice and identity. Normalizing sociotechnical engagement matters because it aligns with broader motivations introduced in the literature, producing globally competent engineers who can navigate diverse cultural and ethical contexts [3], improving employability in an increasingly interconnected workforce [5], and fostering graduates equipped to address grand challenges related to sustainability, equity, and public trust. By embedding these competencies early and sustaining them throughout the curriculum, engineering programs can prepare students not only to do engineering, but to lead responsibly in a global society.

Conclusions

Across the data, several key findings emerged: (1) Students entered the course with an appreciation for technical communication, thinking about ethics, and considering social impacts, which were then strengthened over the course of their first year. (2) Students often struggled to integrate sociotechnical considerations into design decision-making. (3) Structured reflection prompts required students to consider sociotechnical aspects of design and may have started to foster an awareness of sociotechnical dimensions of engineering. (4) Students' reflections revealed that sociotechnical thinking is not yet central to their understanding of the engineering profession.

Introductory courses can catalyze awareness and valuation of sociotechnical dimensions, particularly through structured reflection and collaborative design. Yet, without sustained pathways and intentional scaffolding, students' engagement in sociotechnical thinking remains fragile, tending to be overshadowed by technical mastery and prestige norms. Positioning engagement in sociotechnical thinking as a core competency to be taught, practiced, assessed, and refined will better prepare graduates to act as both technical experts and socially responsible professionals.

Future Work

Future research will continue to examine an expanded set of reflective assignments, including a projected career plan reflection, which may provide insight into students' values and long-term goals as related to societal concern. Additionally, investigating how emerging technologies (e.g., AI tools) influence skills in sociotechnical thinking is critical given their growing role in engineering workflows. AI-tools may introduce both risks (e.g., automation bias, decontextualized solutions) and opportunities (e.g., rapid stakeholder mapping, scenario analysis) for sociotechnical thinking practice.

Finally, future work might focus on designing and assessing a multi-year curricular thread that sustains critical thinking, ethical reasoning, and social accountability beyond the first year. This includes embedding scaffolds into design projects, aligning rubrics with sociotechnical outcomes, and reinforcing these practices through iterative reflection. Longitudinal studies linking these interventions to capstone performance, internship evaluations, and professional identity formation will be essential for understanding how early exposure translates into sustained practice.

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