Sociotechnical Habits of Mind: Initial Survey Results and their Formative Impact on Sociotechnical Teaching and Learning

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Introduction and Background

Within the United States, most engineering degree programs are dominated by engineering science courses that consist primarily of decontextualized (or minimally contextualized), closed-ended problems that fail to illustrate how sociotechnical factors impact problem framing and solution processes ([1]-[4]). Thus, engineering curricula reinforce the notion that technical problem-solving processes can be separated from the social context in which the problem emerged—and in which the solution will reside. In contrast, practicing engineers acknowledge the importance of social contexts and diverse perspectives in their work ([5]-[9]). Students within such traditional curricula often incorrectly expect engineering and social problems to be separate from each other based on their experiences in the classroom, leaving them ill-equipped to think critically about the ambiguity of sociotechnical problems that they will encounter in the workforce [7].

This misalignment is concerning for many reasons. Stevens and collaborators point out that:

> "Students often have vague images of professional engineering work, and the images they do have are strongly colored by the experiences in their educational careers…As a result, students often ignore, discount, or simply do not see images of engineering that emphasize its nontechnical, noncalculative sides and its non-individual aspects" ([6], p. 120).

Similarly, Jonassen also notes problems in the discrepancy between engineering problems solved by students and practitioners: "Learning to solve classroom problems does not effectively prepare engineering graduates to solve workplace problems" ([7], pp. 103-104). When a practicing engineer fails to consider social contexts that shape and are shaped by their designs and to incorporate diverse perspectives into the problem framing and solution process, concerns emerge. The stakeholders that this engineer serves may suffer, the engineer's company may experience costly project delays or cancelations, and the reputation of the engineering profession may be damaged.

Prior research on engineering practice accentuates why sociotechnical thinking matters. For instance, one decade-long study in Australasia involved over 300 interviews with practicing engineers, survey data from nearly 400 engineers, and multiple years of participant observations of engineers at work. That study concluded that those who remained in and found satisfaction in engineering were those who recognized the important interplays between technical and social dimensions of framing and solving problems [5]. Studies in US and UK contexts have come to similar conclusions: engineering is a sociotechnical field of practice ([6], [10]). Despite such studies, engineering courses frequently continue to separate the social and the technical, which only exacerbates the disconnect and the differences between engineering education systems and engineering practice.

We hypothesize here that many engineering students are ill-prepared to approach the framing and solving of engineering problems using a sociotechnical framework. Upon graduation, these engineers may believe that their job is to solve technical problems without considering project-relevant social constraints, impacts, or consequences, and without an understanding of how social elements shape technical ones and vice versa ([4], [11]-[16]).

This paper provides noteworthy qualitative and quantitative results from a survey instrument developed and designed as described in a prior paper [3]. This survey is one of several data sources being used to measure the sociotechnical thinking of engineering students at two Western U.S. universities: the Colorado School of Mines (CSM) and the University of Colorado Boulder (CU). In this paper, sociotechnical thinking is defined as "the interplay between relevant social and technical factors in the problem to be solved" ([3], p. 1). However, we did not provide this definition to students responding to our survey, instead allowing meaning to emerge from the data they provided.

The goals of our survey are to

1. Quantify student self-reports on their perceptions of the importance of different forms of sociotechnical thinking.
2. Measure students' perspectives on engineering habits of mind and the role of sociotechnical considerations in engineering practice.

In this paper, we present survey results from the first two semesters of implementation, Spring and Fall 2018. Our overall project research questions can be found in Appendix B.

In the remainder of this paper, we describe the survey in more detail, including methods for implementation and analysis as well as results and limitations. We conclude by summarizing the work and describing ongoing and future work within the project, providing the survey itself in Appendix A. The overall project's research questions are then provided in Appendix B.

Methods

This survey was used as part of the current research to measure sociotechnical thinking at CSM and CU in the Spring and Fall of 2018, with details shown in Table 1. All appropriate human subjects' procedures were followed according to our institutions' policies.

As indicated in Table 1, this survey was administered to a total of 543 students in classes situated in the first, second or third year of the engineering curriculum. All three courses are taught in engineering colleges, ranging from a first-year introductory design course ("Course 1: *Engineering Projects*"), open to students from any major, to a second-year design course for mechanical engineering students ("Course 2: *Introduction to Mechanical Engineering: Programming and Hardware Interface*") to a junior-level core engineering science course that predominantly enrolls electrical engineers ("Course 3: *Fundamentals of Engineering Electromagnetics*").

For each administration, students were provided with sufficient time to complete the survey in-class either via paper or online. For Course 1, our survey was part of a larger online survey for course improvements for which students were allocated 20 minutes. In this class, following IRB protocols approved by CU, students were required to submit answers to the broader survey but voluntarily selected a checkbox to indicate whether their answers could be used for research; only those who agreed have been considered in this research. In Courses 2 and 3, where the survey was voluntary, students were offered 10-15 minutes to complete our survey in class and were informed that survey completion could improve teaching in future semesters but were not offered additional incentives.

Table 1: Survey administration methods for three classes at two universities across two semesters.

Course	Spring 2018	Fall 2018
"Course 1" - First-year engineering design course (CU)	▪ Survey administered via paper in the seventh week of the semester ▪ n = 21 responses ▪ Survey version 1 [3]	▪ Survey administered online in the first week of the semester ▪ n = 329 responses ▪ Survey version 2 (Question #10 updated; see Appendix A)
"Course 2" - Second-year introduction to mechanical engineering course (CSM)	▪ Survey not administered	▪ Survey administered via paper in the second week of the semester ▪ n = 148 responses ▪ Survey version 2 (Question #10 updated; see Appendix A)
"Course 3" - Third-year engineering science – electromagnetics – course (CSM)	▪ Survey administered via paper in the seventh week of the semester ▪ n = 32 responses ▪ Survey version 1 [3]	▪ Survey administered via paper in the fifth week of the semester ▪ n = 13 responses ▪ Survey version 2 (Question #10 updated; see Appendix A)
Total Responses	▪ N = 53	▪ N = 490

In Spring 2018, the survey was offered slightly later in the semester (week 7) than in Fall 2018 (weeks 1-5). In both semesters, the survey was administered prior to any classroom discussions concerning sociotechnical thinking. The purpose of this administration was to gather initial data that would describe students' sociotechnical thinking before receiving instruction that addresses or develops their understanding of this concept. In the future, we will use this instrument to measure how students' sociotechnical thinking changes from before to after the in-class intervention(s). A primary contribution of the current paper is understanding what engineering students know intuitively or based on prior experiences about sociotechnical thinking. That is, this survey data provides a snapshot of students' prior knowledge and assumptions on sociotechnical thinking and associated engineering habits of mind. Additionally, the inclusion of two universities and courses at multiple education levels supports a comparison of sociotechnical thinking as it occurs in these different academic contexts.

Thematic coding methods for open-ended student survey responses focused on statements related to sociotechnical thinking. In Spring 2018, two trained research members coded the qualitative survey responses separately using the qualitative data analysis software NVivo, and each wrote an individual summary analytic memo ([18], [19]). The two researchers then compared thematic codes and memos, and wrote a consensus memo. For the Fall 2018 data, the same general process was followed, but this time with four members of the research team instead of two. The group met as a whole to discuss and refine the themes. They also discussed and compared interpretations, contributing to the inter-rater reliability. The codebook that emerged from the

Spring 2018 analysis was provided to all researchers analyzing the Fall 2018 data, but researchers were not constrained by this codebook. For both semesters, the data was analyzed using a qualitative analysis framework based on the idea that themes and categories are grounded in the data, emerging within the analysis process instead of being pre-defined. In this paper, student responses – i.e., the data – are included for each theme that emerged from the data, a method described in [20].

Results, Findings, and Discussion

The students in our study come from different backgrounds, hold a variety of identities, attend different universities with unique academic cultures, and are in different stages of their undergraduate education. In this section, we present noteworthy quantitative results from the survey, indicating potential opportunities and barriers for sociotechnical integration within the three classes.

Quantitative Results

Section 1 of the survey (see Appendix A) consists of Questions 1-6 and seeks to characterize students' perceptions of engineering practice. The survey begins with Question 1, which asks students to state the importance of nine different skills to engineering practice. Figure 1 displays four of the skills identified in this question that show noteworthy discrepancies across the three courses between the percentage of students choosing "Extremely" + "Very" important and "Somewhat" + "Not at all" important.

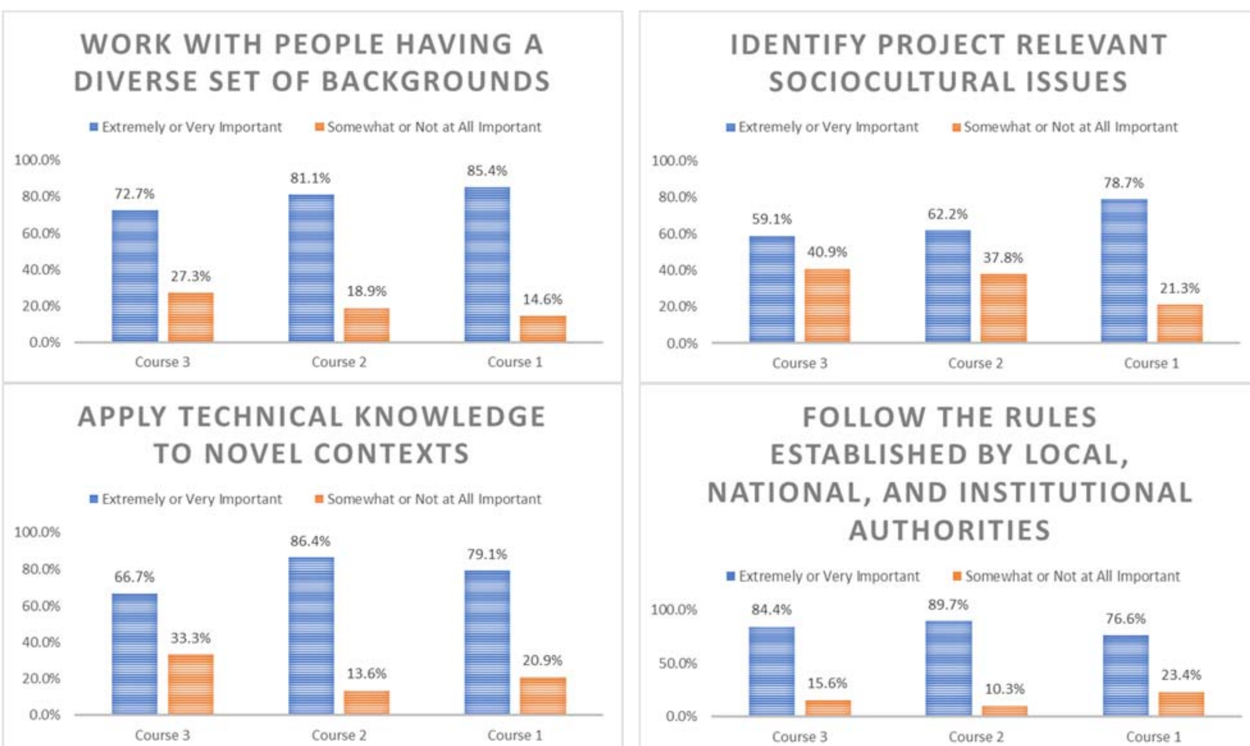

Figure 1: Selected Question 1 results showing differences in student perceptions of the importance of various skills for engineering practice. Data is combined from Spring and Fall 2018 for Courses 1 and 3 but is from Fall 2018 only in Course 2.

In particular, students enrolled in Course 3 (CSM), which is the third year electrical engineering course, are less likely to report that **working with people having a diverse set of backgrounds** is extremely or very important (73%) within engineering practice than students enrolled in Course 2 and Course 1 (81% and 85%, respectively). Students in Courses 3 and 2, both at CSM, are less likely to say that **identifying project-relevant sociocultural issues** is extremely important (59% and 62%, respectively) than students in Course 1 at CU (79%). Although the survey does not provide sufficient information to determine reasons for these differences, it seems noteworthy that these sociotechnical skills seem to decrease in importance with course year. This result suggests that differences between core engineering science courses and introductory engineering courses in influencing students habits of mind might be worthy of investigation.

Other noteworthy differences in Question 1 responses included fewer students in Course 3 (67%) placing high importance on **applying technical knowledge to novel contexts** than in Courses 2 and 1 (86% and 79%, respectively), and fewer students in Course 1 (77%) placing high importance on **following the rules established by local, national, and institutional authorities** (84% in Course 3 and 90% in Course 2). Since Course 1 is at a different university, it may be interesting to try to understand whether institutional factors play a role in this discrepancy.

The second question of the survey, which asks students to rate the importance of various considerations in engineering practice, shows a discrepancy in the importance of social considerations within engineering practice, as shown in Figure 2. At CSM, only 62% of students in Course 3 and 58% of those in Course 2 indicated that **social considerations** were extremely or very important, compared to 73% of students in Course 1 at CU. As with Question 1, this result also suggests that university-level impacts might be worthy of study. Course 1 (86%) and 2 (83%) students were more likely to say that **"manufacturability"** is extremely or very important than students in Course 3 (69%). The remaining considerations – economic, environmental, ethical, health and safety, and technical – showed substantially smaller differences among the three courses.

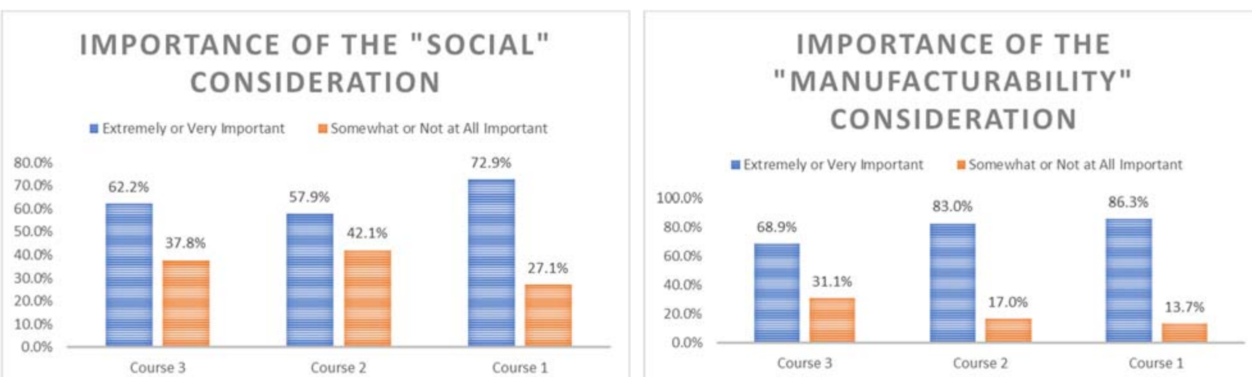

Figure 2: Selected Question 2 results showing possible differences in student perceptions of the importance of "Social" and "Manufacturability" considerations for engineering practice. Data is combined from Spring and Fall 2018 for Courses 1 and 3 but is from Fall 2018 only in Course 2.

The largest discrepancies in Question 3, which asks students how often they believe practicing engineers incorporate various considerations into their work, were related to students' views of environmental and social considerations. As shown in Figure 3, in both cases the expected percentages increase from Course 3 to Course 1; viewed from a time perspective, it declines from first to third year. One hypothesis is that this trend may be related to an increase in the total number of classes students take from their first through third years, but further analysis would be required to assess its validity. For the environmental consideration, 63% of students in Course 1 expected weekly to daily incorporation compared to 50% of students in Course 2 and 35% in Course 3. For social considerations, weekly to daily incorporation was expected by 60% of Course 1 students, 48% of Course 2 students, and only 32% of Course 3 students.

Figure 3: Selected Question 3 results showing how frequently students believe practicing engineers incorporate environmental and social considerations. Data is combined from Spring and Fall 2018 for Courses 1 and 3 but is from Fall 2018 only in Course 2.

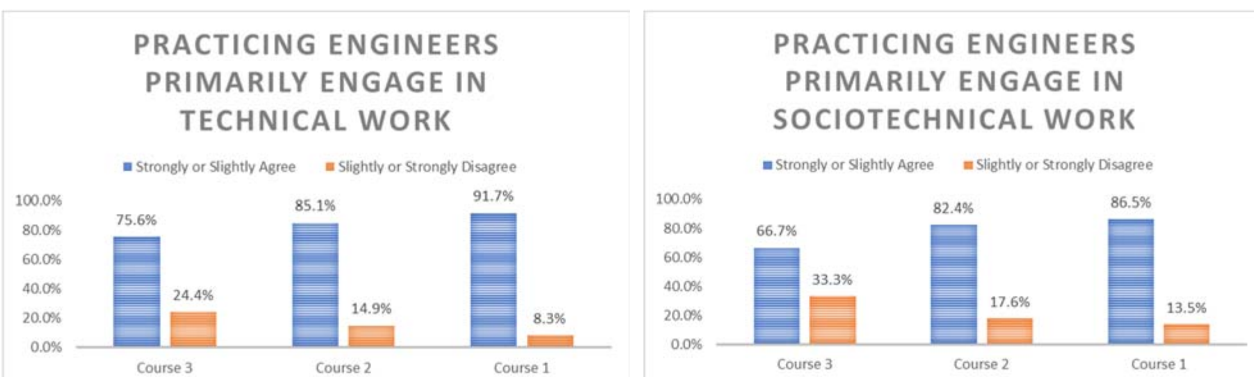

Figure 4: Selected Question 4 results showing differences in student agreement with the statement "Practicing engineers primarily engage in sociotechnical work." Data is combined from Spring and Fall 2018 for Courses 1 and 3 but is from Fall 2018 only in Course 2.

Consistent with what we found in previous literature, a large majority of students enrolled in all three courses either slightly or strongly agreed with the statement that "Practicing engineers primarily engage in technical work" (Question 4, shown in Figure 4), with 92%, 85%, and 76% of students in Courses 1-3 agreeing with the statement, respectively. However, 87% and 82% of students enrolled in Courses 1 and 2, respectively, also agree with the statement that "Practicing engineers primarily engage in sociotechnical work," while only 67% of students in Course 3 agree with the statement, as shown in Figure 4. These results may be linked to those from

Question 2: if students do not believe that social considerations are important, they may be less likely to believe that practicing engineers engage in sociotechnical work, and vice versa. Similarly, there may be a link to the Question 3 results: less frequent incorporation of social considerations is likely to reduce the time primarily engaged in sociotechnical work.

Question 5 elicited student perspectives on whether it is appropriate to consider technical, social, or sociotechnical considerations when solving problems in workplace contexts. Since the students in the three classes provided more consistent responses than they had for Questions 1-4, selecting " Recognize project-relevant interplays between technical and nontechnical considerations" more often than any other answer in all three classes, we omit detailed results from Question 5. Question 6 is open-ended and examined in the qualitative analysis in the next subsection.

The second section of the survey, which consists of Questions 7-11, asks multiple choice questions intended to provide some insight into why students gave the answers they did in the first section. Both Questions 7 and 9 resulted in the majority of students across all three classes selecting a single answer. This common answer is bolded here, followed by the percentage of students that selected it within each course).

> Question 7. The most important reason that engineers have professional obligations to society is **science and technology can affect the public in profound ways.** (90%, 79%, and 89% in Courses 1, 2, and 3, respectively)

> Question 9. Social responsibility is often expressed as **engineers' obligation to the public** (74%, 81%, and 68% in Courses 1, 2, and 3, respectively)

For Question 8, one response was selected more often than others by students in all three courses, though not by majority of students in Course 1:

> Question 8. Technical decisions can have long lasting social consequences because **once technical decisions are in place, it often becomes difficult for engineers to change them** (47%, 59% and 68% in Courses 1, 2, and 3, respectively)

The consensus among students across the three classes to these answers may suggest an opportunity for how to motivate students to learn to think sociotechnically, drawing on their understanding of the impact of science and technology on the public, their recognition that engineers may have public obligation, and the difficulty in fixing problems once decisions are made.

The options provided for Question 10 were updated for Fall 2018 after many Spring 2018 respondents took issue with the options available to them, explaining their concerns in the open-ended Question 11. Table 2 displays the updated question and options. The impact that this change may have had on students' responses is currently being examined. Pending the results of this analysis, the data from this question is not included here.

Table 2: Student-recommended changes for Question 10

	Spring 2018	Fall 2018
Question wording	Engineers have special obligations to society because [Select one]	Engineers have special obligations to society *primarily* because [Select one]
Options	□ Engineers often have special expertise in fields that ordinary citizens do not have □ Engineering research must comply with applicable environmental laws □ Employer reputation depends on the work of engineers □ Engineering research is often backed by federal funding	□ Engineers often have special expertise in fields that ordinary citizens do not have □ Engineering must comply with applicable laws and regulations □ Engineering decisions can impact individuals, communities, and the broader public positively and/or negatively □ Employer reputation and profitability depend on the knowledgeable, skillful practices of engineers □ Fulfilling such obligations upholds the reputation of the engineering profession

The third section of the survey, which collects demographic information about the survey, is outside of the scope of this paper. Some results related to this demographic information, specifically how students identifying with different genders answer the questions differently, are presented in [24].

Qualitative Findings

The survey contains three open-ended questions, Questions 6, 11, and 12, which were analyzed using qualitative methods as described in the *Methods* section. In **Spring 2018**, the three most relevant cross-cutting themes that emerged in responses to these questions, along with brief explanations, were identified by two research team members. They are listed and briefly explained here, with the bulk of this section focused on Fall 2018 results below when more data was available.

1. Spring 2018 Theme 1: Sociotechnical Integration/Dualism: Students have a range of views on whether (and the degree to which) the social and technical dimensions of engineering problems are integrated or divided. Inevitably, students' position on a continuum—ranging from social-technical dualism to sociotechnical integration—will have a strong influence on their perspective regarding the need for and value of sociotechnical thinking. Social-technical dualism refers to an artificial separation of the social and technical dimensions of engineering, with priority placed on the technical [15]. One subtheme on sociotechnical issues involved engineers' notions on the proximity to social dimensions, which influenced how they see organization and division of labor.

2. Spring 2018 Theme 2: Engineers' Social Responsibility/Privilege and Power: Students provided several responses that were not directly solicited on engineers' broader responsibility to society given the amount of power and privilege they hold.
3. Spring 2018 Theme 3: Motivations and Influence on Perspectives: Some students shared various motivations on why they wanted to become engineers. They also conveyed how their perspectives on the survey were shaped by various lived experiences, while many also acknowledged that they do not yet have the experience to answer many of the survey questions as experts.

In **Fall 2018**, more data was available, leading to additional analysis opportunities and deeper theme development. From this data and independently of the Spring 2018 themes listed above, two major themes were identified by four team members:

4. Fall 2018 Theme 4: Relationship between the Social and Technical Dimensions of Engineering Problems
5. Fall 2018 Theme 5: Constructions of Engineering as a Field of Practice

The additional data available in Fall 2018 enabled us to further expand these themes and to identify subthemes, as discussed in the sections that follow.

4. Fall 2018 Theme 4: Relationship between the Social and Technical Dimensions of Engineering Problems

Students expressed perspectives on the relationship between social and technical dimensions of engineering problems – an extension from Theme 1 in Spring 2018 – on two axes, as shown in Figure 5. In this visualization, the horizontal axis ranges from technical-social dualism on the left to sociotechnical integration on the right, and the vertical axis represents how much responsibility engineers have over the social and technical dimensions of engineering problems. Illustrative quotes are provided for each case. By sorting student perspectives into these four quadrants (I-IV), our team can better represent patterns in students' perspectives, attempt to understand whether any resistance to sociotechnical integration is a result of dualism versus assumption of whether an engineer should be responsible, and plan pedagogical approaches for the classroom.

Theme 4a) Spectrum from technical-social dualism to sociotechnical integration

Technical-social dualism is the left half of the horizontal axis in Figure 5, encompassing student responses in the second and third quadrants. This perspective includes student responses that cleanly divide social dimensions of engineering problems from technical dimensions of engineering problems, and/or students who state or imply that a clean divide is always possible. In addition to the characteristic quotes above, student quotes displaying a dualistic perspective include:

- "Technical considerations are the most important, than (sic) comes non technical" -F18 Course 2 #23
- "social science isnt (sic) a real science"-F18 Course 2 #121

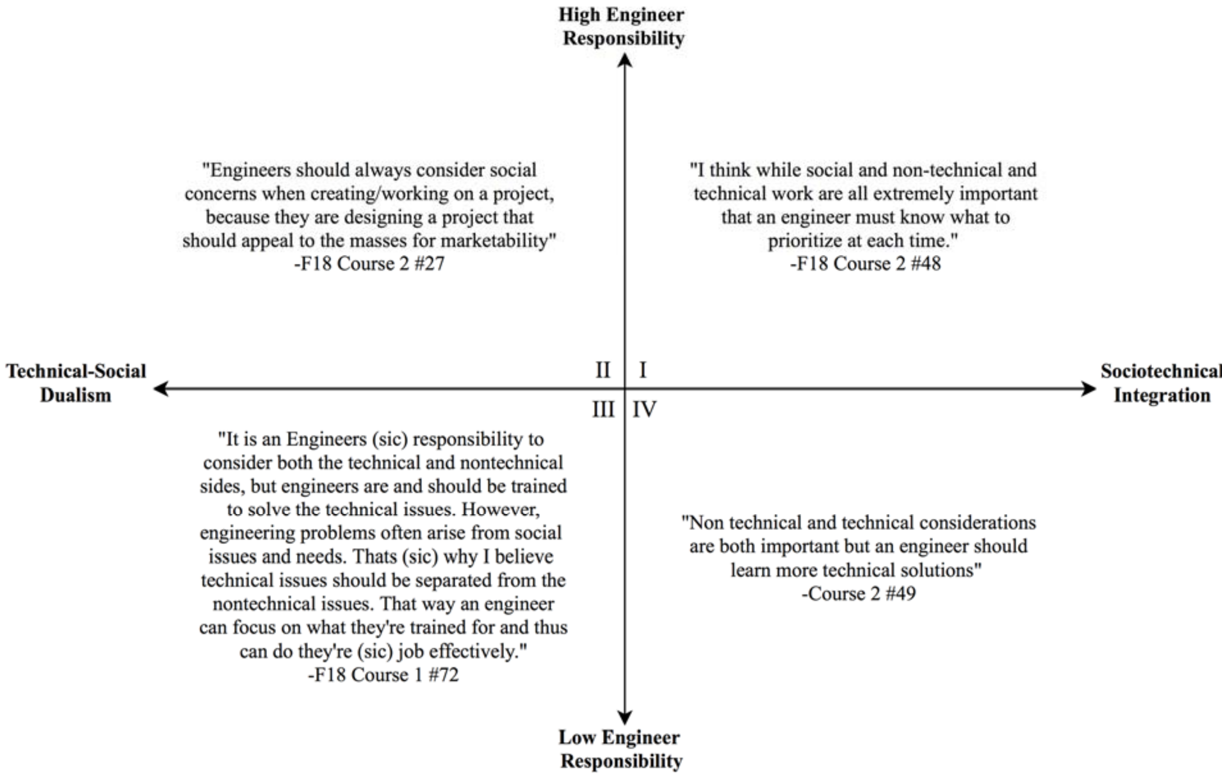

Figure 5: The two-dimensional, four-quadrant sociotechnical spectra illustrating Theme 4 with characteristic student quotes in each quadrant. "High/Low Engineer Responsibility" on the vertical axis refer to the level of responsibility assigned to the engineer, whether internally or by an external source.

Sociotechnical integration is represented on the right side of Figure 5, encompassing student responses in the first and fourth quadrants. This perspective intertwines the social and technical dimensions of engineering into an inseparable, combined field. In addition to the characteristic quotes within Figure 5, student quotes displaying an integrated perspective include:

- "Engineers should be able to effectively communicate the work that they have completed. In order to do so, engineers must integrate a certain degree of balance between technical and nontechnical considerations." -F18 Course 1 #123
- "I think engineering encompasses many different values and considerations in the job, so one thing is not more important than the other." -F18 Course 1 #278

Many of the quotes across the dualism-integration axis point out that thoroughly addressing the social and technical aspects may require a team composed of different disciplines. Finding the right balance between the social and technical dimensions depended on several variables. Students referenced considering the field of engineering that they are working in and the details of the given engineering project. The impact of these variables is captured well by the "F18 Course 1 #123" quote above and the following one:

- "Question 4, I don't think any engineer is doing just technical or just working on integrating both. The job requires both different duties and different parts of the design process. For Questions 2 and 3 I think all thinks (sic) should be considered in engineering, but not used equally and it depends on the project" -F18 Course 2 #19

Theme 4b) Spectrum on the degree to which sociotechnical integration in the problem framing and solving process is part of an engineer's responsibility.

The vertical axis in Figure 5 indicates the degree to which responses imply that social-technical interplays in engineering are the responsibility of the engineer (vs. that of some other party). Some student responses demonstrated a hands-off approach to the social, either implying that social dimensions are out of the scope of engineering or that a different field is responsible for the social dimensions. The quotes in quadrants III and IV in Figure 5 (lower portion) demonstrate this perspective. Quadrants I and II represent a student perspective that considers both social and technical dimensions of engineering as a part of engineers' problem framing and solving responsibilities.

In some cases, responses aligning with the top half of Figure 5 (high engineering responsibility for sociotechnical elements of engineering design) are aligned with a sense of engineering privilege leading to (sociotechnical) engineering obligation. Privilege here refers to the notion that engineers have access to particular forms of knowledge, power, people, and processes that non-engineers do not have (the same) access to, resulting in a unique obligation for engineers. For example:

- "In number ten, engineers often have access to people and materials that can change society much more than other professions. For this reason, they have special obligations because they can drastically change the world." -F18 Course 1 #104
- "For question 10 it is also true that engineers have expertise is certain fields that normal citizens do not" -F18 Course 2 #27

The difference between "engineers" and "normal citizens" in this second example of obligation also links to Theme 5a later in this section, namely an engineering attitude that can express a sense of obligation that appears to be motivated by service and collaboration in some cases vs. a sense of superiority in other cases.

This sense of sociotechnical obligation can take on a wide variety of flavors, from economics to professional ethics to individual morals:

- "Studying how past engineers chose certain unethical decisions based on monetary decisions makes me believe that should be corrected. Eningeers (sic) should strive for bettering society, not just themselves" -F18 Course 2 #114
- "My university sponsored extracurricular activity is AFROTC, which requires me to consider integrity, responsibility, service, and exellence (sic) as the moral pillars by which I live my life" -F18 Course 2 #85
- "Engineers are expected to be good general people who try to consider all involed (sic) parties" -F18 Course 2 #104

The qualitative analysis suggests that students understand that engineering work impacts society, but hold a variety of perspectives on what that means. Since the majority of respondents are first or second-year undergraduates, additional relevant experience gained in later years may shift student understanding.

5. Fall 2018 Theme 5: Constructions of Engineering as a Field of Practice

The second theme that emerged from the Fall 2018 qualitative data analysis loosely aligned with the question of, "What is engineering?," which can provide information about students' engineering habits of mind. Several perceptions emerged on how engineering is constructed as a field of practice. These perceptions can include three subthemes aligned with values, attitudes, and skills.

Theme 5a) Values on Stakeholder Engagement and Public Impact

The "values" subtheme emerged specifically with respect to stakeholder engagement and public impact. Several responses indicated recognition that engineering for others is important in its own right. Since many people are affected by engineering products and services, stakeholder engagement is a necessity. For example, respondents wrote:

- "Engineering isn't a practice that stands alone…" – F18 Course 2 #93
- "With great power, comes great responsibility. We must use the tools of innovation wisely, to impact people in ways that develop positive cultures and accelerate humanity forward!" – F18 Course 1 #232

Theme 5b) Attitudes: Engineering Impacts on Society and "Social" Aspects of Engineering

The "attitudes" subtheme of Theme 5 is closely related to the high vs. low engineering responsibility subtheme 4b) described above and illustrated in Figure 5. As noted in the Theme 4 subsection, survey responses suggest that students are keenly aware of the social impacts engineers can have on society, but can have a wide variety of attitudes about how to make use of that recognition:

- "...engineers often have access to people and materials that can change society much more than other professions. For this reason, they have special obligations because they can drastically change the world." -F18 Course 1 #104
- "Engineers are people too therefore (sic) they should care how their work affects the public." – F18 Course 1 #247

Various perspectives emerged for what "social" aspects of engineering entail, including "marketability":

- "Engineers should always consider social concerns when creating/working on a project, because they are designing a project that should appeal to the masses for marketability." – F18 Course 2 #27

Environmental and manufacturability elements of "social" also arose in the responses:

- "Engineers primarily focus on technical aspects, but also consider social and environmental aspects coordinately." – F18 Course 2 #19
- "When you are brainstorming a project, the manufacturability of a project is less important than it is in the latter design phases." – F18 Course 1 #238

Theme 5c) Professional Skills (teamwork, communication, diversity appreciation)

The skills subtheme surfaced as a significant number of the responses suggested that students understand that engineering is often not a solo effort. Engineering involves substantial amounts of teamwork and communication in order to co-create solutions successfully. Specific responses addressing teamwork and communication suggest that many students consider these concepts to be important professional skills:

- "In my experience, it has proven to be really unreasonable to say ONE engineer can address all technical and nontechnical concerns. Hence, why I have suggested that one forms a team of people of various specialties in order to give all technical and nontechnical considerations the time and effort they deserve - though all parties must be aware of the issues and their relationships." – F18 Course 1 #232
- "I feel that regardless of a person's background it is just generally important to work with people. We are all people regardless of skin color, race, ethnicity, etc. If we all have the same drive to do better in the world and accomplish something great then it doesn't matter who it is you work with. Just people." – F18 Course 1 #303

Implications

Two major factors shape student perspectives in this sociotechnical thinking model: an understanding of the value of sociotechnical integration and an understanding of the degree to which practical engineering work requires sociotechnical integration. Thus, certain implications emerge for engineering education. We propose that a pedagogical approach that emphasizes practical applications of key technical concepts via real-world engineering examples of sociotechnical integration is likely to be more effective in promoting sociotechnical habits of mind than an approach that emphasizes decontextualized technical examples. Such an approach would have the goal of shifting student perspectives upward on the vertical axis in Figure 5 (augmented recognition of engineers' sociotechnical responsibility) as well as to the right on the horizontal axis (more sociotechnical integration), preparing them for the world of practicing engineers. This example or case-study-based approach would require interventions that are tailored to each engineering field and class.

One possible conclusion that we can draw from the two-dimensional sociotechnical spectra representing Theme 4 ("Relation between the Social and Technical Dimensions of Engineering Problems") is that students' perceptions of how social and technical dimensions of engineering are divided in the workplace may affect how they as individuals choose to prioritize social and technical aspects in their own problem framing and solving processes. For example, while many student quotes place highly (toward the right) on the horizontal axis of Figure 5, many also place low on the vertical axis. It is therefore possible that students' approach toward sociotechnical elements in engineering originates from a misconception of how integrated social and technical elements are in engineering practice (thus causing them to not feel responsible for such integration), as evidenced by the above literature review.

Limitations

Several practical elements have led to legitimate questions about limitations of the survey and its implementation. In particular, the delay in administering the survey during our first semester of research, Spring 2018, was caused by a delay in its creation and resulted in its administration in the seventh week of the semester. This delay may have led to differences in results when comparing Spring 2018 results with the subsequent (Fall 2018) administration in the first week of the semester. We have not yet determined whether significant differences exist in the results that are likely linked to this time delay vs other factors; if so, our subsequent analysis in 2019 and beyond may discard the Spring 2018 data.

Based on the results collected to date, it is not possible to determine the impact of using paper vs. online survey. Our goal is to transition all survey administrations to online for subsequent semesters to eliminate this variable.

Students were purposely not provided in-course information about the meaning of "sociotechnical" prior to the survey administrations reported in this paper, though certainly they could have heard the term outside of the courses in the study. Additional terms that could have caused confusion, such as "social" and "manufacturability," were examined via the Think Aloud protocol described in [3]. As a result of this protocol, "manufacturability" was defined as "the ability to manufacture a given design" within the survey itself. It remains possible that other terms could have confused some survey respondents. As a result, we continue to evaluate the qualitative results to increase our understanding of any points of confusion.

Although our research explicitly considers three courses of different formats, different student levels, and at two universities, many additional variables exist that increase the difficulty of drawing comparisons. Impacts of specific instructors, and whether students answer questions in a manner that they believe the instructors want to see, are difficult to fully determine from one implementation of the survey alone, except in rare cases of free responses addressing these issues directly. In addition to further analysis (outside of the scope of this paper) of additional project data in combination with the survey data, ensuring that students understand that their instructors are not performing the detailed survey analysis will help to mitigate concerns that students may answer in the manner that they believe they are expected. The influence of different instructors within a specific class is outside of the scope of this paper.

The survey alone is not well-suited to assess which specific pedagogical elements were more influential in promoting sociotechnical thinking or shaping engineering habits of mind. Instead, the other data sources generated within the overall project – namely, focus groups, assignment data, and faculty reflection logs – are being analyzed to better answer this question. Analyzing these data is a future part of our broader project.

Finally, the results presented here cannot be generalized beyond the current population, a shortcoming that is under consideration in the subsequent years of the broader project.

Conclusions and Future Work

In this paper, we have described noteworthy results from two semesters administering a survey to measure elements of sociotechnical thinking across three engineering classes at two universities. The classes range from first through third year courses and draw students from a variety of engineering, and some non-engineering, majors, with a substantial number of the students majoring in electrical and mechanical engineering. The survey is designed to be administered at the beginning and end of a semester in which sociotechnical elements were integrated into the course, although this paper only describes pre-integration results.

Through analysis of quantitative data, it appears that discrepancies exist between first, second, and third year students responding to some sociotechnical engineering questions. In four of the cases presented, we observed a decline in positive responses to sociotechnical elements of engineering from the first and second to the third year course. These cases included: work with people who define problems differently, identify project relevant sociocultural issues, work with people having a diverse set of backgrounds, the importance of "social" considerations in engineering, and whether students agree that "practicing engineers primarily engage in sociotechnical work."

Particularly due to student responses to Questions 7-9, the consensus among students across the three classes may yield insight into how to motivate students to learn to think sociotechnically. Specifically, such motivation might come by drawing on their understanding of the positive impact science and technology can have on society and the public, their recognition that engineers likely have obligations to society and the public due to access to specialized knowledge, power, people, etc., and the real difficulties in fixing problems once decisions are made.

Our qualitative data analysis was conducted separately in the two semesters surveyed, with far more data available in Fall 2018 and thus more substantial analysis from this semester. During Fall 2018, two prominent themes emerged from the analysis of the sociotechnical thinking survey: *Theme 4: Relations between the social and technical dimensions of engineering problems,* and *Theme 5: Constructions of engineering as a field of practice*. Subthemes emerged from each theme that may provide insight into opportunities for teaching sociotechnical thinking to engineering students at the three grade levels studied. In particular, for Theme 4, helping students to achieve a higher sense of the responsibility of practicing engineers toward society could influence their understanding of the interconnectedness of the social and technical.

Several limitations surfaced with our survey. First, the survey will need to be combined with the other data sources to fully answer our overall project's research questions (Appendix B), and these additional sources are outside of the scope of this paper. Second, more data is needed to compare pre- and post-integration results to measure any changes in sociotechnical thinking that may result from sociotechnical integration. Also, further analysis is needed to better characterize similarities and differences across institutions and other factors beyond course year.

Future work will focus on addressing these limitations. In addition, we are also interested in these questions, among others:

- Can we articulate a more explicit conceptualization of "habits of mind" and the means to understand students' habits of mind that can support both our own research questions (Appendix B) and those of others in this research area? This area may also be supported by our additional data sources within this project that are not reported in this particular paper.
- What can help explain why students at CSM were much more likely to predict that following the rules established by local, national, and institutional authorities is extremely or very important than those at CU?
- What factors impact the steady decline in expected frequency of incorporations of social and environmental considerations into engineering practice from the first through the third year courses?
- Will distinct attitudes toward sociotechnical thinking emerge between students in Course 1, 2, and 3? If so, can this be attributed to their year in school, major, gender (see also [24]), or other factors?
- Are there particularly promising pedagogical methods that are more successful in promoting sociotechnical thinking or shaping engineering habits of mind across the

courses in our study, and can these contribute to "best practices" for teaching sociotechnical thinking in other courses and other institutions?

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References

[1] Huff, J., "Humanizing Signals and Systems: A Reflective Account," in *Proceedings of the ASEE Annual Conference and Exposition*, Seattle, WA, 2015.

[2] J. Lucena and J. A. Leydens, "From sacred cow to dairy cow: Challenges and opportunities in integrating of social justice in engineering science courses," in in *Proceedings of the ASEE Annual Conference and Exposition*, Seattle, WA, 2015.

[3] J. Leydens, K. Johnson, S. Claussen, J. Blacklock, B. Moskal, and O. Cordova, "Measuring Change over Time in Sociotechnical Thinking: A Survey/Validation Model for Sociotechnical Habits of Mind: American Society for Engineering Education," in *Proceedings of the ASEE Annual Conference and Exposition*, Salt Lake City, UT, 2018.

[4] J. Leydens and J. Lucena, Engineering justice: *Transforming engineering education and practice*. Hoboken, NJ: Wiley-IEEE Press, 2018.

[5] J. Trevelyan, *The making of an expert engineer: how to have a wonderful career creating a better world and spending lots of money belonging to other people*, Leiden, The Netherlands: CRC Press, 2014.

[6] R. Stevens, A. Johri, and K. O'Connor, "Professional engineering work," *Cambridge handbook of engineering education research*, New York, NY: Cambridge University Press, 2014, pp. 119-137.

[7] D. Jonassen, "Engineers as problem solvers," in *Cambridge Handbook of Engineering Education Research*, New York, NY: Cambridge University Press, 2014, pp. 103–118.

[8] G. Downey, "Are engineers losing control of technology?: From 'Problem Solving' to 'Problem Definition and Solution' in engineering education," *Chemical Engineering Research and Design*, vol. 83, no. 6, Jun. 2005, pp. 583–595.

[9] G. Downey, J. Lucena, B. Moskal, R. Parkhurst, T. Bigley, C. Hays, B. Jesiek, L. Kelly, J. Miller, S. Ruff, J. Lehr, A. Nichols-Belo, "The globally competent engineer: Working effectively with people who define problems differently," *Journal of Engineering Education*, vol. 95, no. 2, 2006, pp. 1–16.

[10] R. Martin, B. Maythan, J. Case, and D. Fraser, "Engineering graduates' perceptions of how well they were prepared for work in industry," *European Journal of Engineering Education*, vol. 30, no. 2, (2005), pp. 167-180.

[11] A. Valderamma Pineda, "What Can Engineering Systems Teach Us about Social (In)justices? The Case of Public Transportation Systems," in *Engineering Education for Social Justice: Critical Explorations and Opportunities*, J. C. Lucena, Ed. Dordrecht, Netherlands: Springer, 2013, pp. 203–226.

[12] L. Winner, *The whale and the reactor: a search for limits in an age of high technology*, Chicago: University of Chicago Press, 1986.

[13] L. Winner, "Artifacts/ideas and political culture," *Whole Earth Review*, vol. 73, 1991, pp. 18–24.

[14] E. Cech, "The (mis)framing of social justice: Why ideologies of depoliticization and meritocracy hinder engineers' ability to think about social injustices," in *Engineering education for social justice: Critical explorations and opportunities*, J. C. Lucena, Ed. Dordrecht; New York: Springer, 2013, pp. 67–84.

[15] E. Cech, "Culture of Disengagement in Engineering Education?," Science Technology Human Values, vol. 39, no. 1, pp. 42–72, Jan. 2014.

[16] D. MacKenzie and J. Wajcman, *The social shaping of technology*, Maidenhead: Open University Press, 1999.

[17] American Association for the Advancement of Science (AAAS), *Science for All Americans*, New York: Oxford University Press, 1990.
[18] A. Bryant and K. Charmaz, *The SAGE handbook of grounded theory*, Los Angeles: SAGE Publications, 2007.
[19] B. Glaser, *Discovery of grounded theory*, 1967.
[20] J. Case and G. Light, "Framing qualitative methods in engineering education research: Established and emerging methodologies," in *Cambridge handbook of engineering education research*, New York: Cambridge University Press, 2014, pp. 535–549.
[21] N. McNeill, E. P. Douglas, M. Koro-Ljungberg, D. J. Therriault, and I. Krause, "Undergraduate Students' Beliefs about Engineering Problem Solving Undergraduate Students' Beliefs about Engineering Problem Solving," *Journal of Engineering Education*, vol. 105, no. 4, 2016, pp. 560–584.
[22] J. Walther, N. Kellam, N. Sochacka, and D. Radcliffe, "Engineering Competence? An Interpretive Investigation of Engineering Students' Professional Formation," *Journal of Engineering Education*, vol. 100, no. 4, 2011, pp. 703–740.
[23] J. Walther, N. Sochacka, L. Benson, A. Bumbaco, N. Kellam, A. Pawley, and C. Phillips, "Qualitative Research Quality: A Collaborative Inquiry Across Multiple Methodological Perspectives," *Journal of Engineering Education*, vol. 106, no. 3, 2017, pp. 398–430.
[24] M. Swartz, J.A. Leydens J. Walter, and K. Johnson, "Is Sociotechnical Thinking Important in Engineering Education?: Survey Perceptions of Male and Female Undergraduates," *Proceedings for the American Society for Engineering Education Annual Conference*, Tampa, FL, 2019.

Appendix A: Survey

Section 1

Instructions: This set of questions asks about your perceptions of the field of engineering practice.

1. Think about **your future role** as an engineer. For each of the following, rate how important you believe each of these **skills** will be when you practice engineering as a professional *by circling* the level of importance that best matches your answer.

Solve technical problems within familiar contexts	Not at all Important	Somewhat Important	Very Important	Extremely Important
Apply technical knowledge to novel contexts	Not at all Important	Somewhat Important	Very Important	Extremely Important
Work with people who define problems differently	Not at all Important	Somewhat Important	Very Important	Extremely Important
Listen to and integrate the perspectives of both engineers and non-engineers	Not at all Important	Somewhat Important	Very Important	Extremely Important
Approach problems that are not clearly defined or with uncertain parameters	Not at all Important	Somewhat Important	Very Important	Extremely Important
Identify project-relevant sociocultural issues	Not at all Important	Somewhat Important	Very Important	Extremely Important
Follow the rules established by local, national, and institutional authorities	Not at all Important	Somewhat Important	Very Important	Extremely Important
Work with people having a diverse set of backgrounds	Not at all Important	Somewhat Important	Very Important	Extremely Important
Acknowledge the strengths and limitations of different forms of knowledge for solving different kinds of problems	Not at all Important	Somewhat Important	Very Important	Extremely Important

2. Think about **your future role** as an engineer. For each of the following, rate how important you believe each of these **considerations** will be when you practice engineering as a professional *by circling* the level of importance that best matches your answer..

Economic	Not at all Important	Somewhat Important	Very Important	Extremely Important
Environmental	Not at all Important	Somewhat Important	Very Important	Extremely Important
Ethical	Not at all Important	Somewhat Important	Very Important	Extremely Important
Health and Safety	Not at all Important	Somewhat Important	Very Important	Extremely Important
Manufacturability*	Not at all Important	Somewhat Important	Very Important	Extremely Important
Technical	Not at all Important	Somewhat Important	Very Important	Extremely Important
Social	Not at all Important	Somewhat Important	Very Important	Extremely Important

*the ability to manufacture a given design

3. How often do you think practicing engineers incorporate each of the following **considerations** in their work? Indicate your answer *by circling* the level of importance that best matches your answer.

Economic	Not at all	Once or twice a YEAR	Once or twice a MONTH	Once or twice a WEEK	Daily
Environmental	Not at all	Once or twice a YEAR	Once or twice a MONTH	Once or twice a WEEK	Daily
Ethical	Not at all	Once or twice a YEAR	Once or twice a MONTH	Once or twice a WEEK	Daily
Health and Safety	Not at all	Once or twice a YEAR	Once or twice a MONTH	Once or twice a WEEK	Daily
Manufacturability*	Not at all	Once or twice a YEAR	Once or twice a MONTH	Once or twice a WEEK	Daily
Technical	Not at all	Once or twice a YEAR	Once or twice a MONTH	Once or twice a WEEK	Daily
Social	Not at all	Once or twice a YEAR	Once or twice a MONTH	Once or twice a WEEK	Daily

*the ability to manufacture a given design

4. Based on your understanding of engineering practice, indicate the degree to which you **agree or disagree** with the statements below *by circling* the level of agreement or disagreement:

Practicing engineers primarily engage in technical work.	Strongly Disagree	Slightly Disagree	Slightly Agree	Strongly Agree
Practicing engineers primarily engage in nontechnical work (e.g., social, cultural, etc.)	Strongly Disagree	Slightly Disagree	Slightly Agree	Strongly Agree
Practicing engineers primarily engage in sociotechnical (integration of technical and social elements) work.	Strongly Disagree	Slightly Disagree	Slightly Agree	Strongly Agree
Social concerns are outside an engineer's responsibilities.	Strongly Disagree	Slightly Disagree	Slightly Agree	Strongly Agree

5. When solving most engineering problems in engineering practice, it is **most appropriate** to [*Select one*]
   - □ Identify all of the technical considerations and separate them from the nontechnical considerations
   - □ Recognize project-relevant interplays between technical and nontechnical considerations
   - □ Integrate all of the technical and nontechnical considerations
   - □ Partner with a social scientist who can handle nontechnical considerations

6. Are there any clarifying remarks you would like to make about your answers to the questions in this section?

Section 2

Instructions: This part of the survey has four questions. For each question, select the one response you think is best.

7. The most important reason that engineers have professional obligations to society is [*Select one*]
   - ☐ Codes of ethics make mandatory statements about social responsibility.
   - ☐ Science and technology can affect the public in profound ways.
   - ☐ Licensure (the obtaining of a professional license) of engineers requires attention to social responsibility.
   - ☐ Social responsibility is required by the U. S. government.

8. Technical decisions can have long lasting social consequences because [*Select one*]
   - ☐ Technical decisions can quickly change research methods
   - ☐ Technical decisions often result in privacy issues
   - ☐ Once technical decisions are in place, it often becomes difficult for engineers to change them
   - ☐ Technical decisions can have short-term effects on how research is carried out.

9. Social responsibility is often expressed as [*Select one*]
   - ☐ Engineers' obligations to the public
   - ☐ Engineers using innovative experimental procedures
   - ☐ How engineers should avoid scientific misconduct
   - ☐ How engineers must protect their data

10. Engineers have special obligations to society *primarily* because [*Select one*]
    - ☐ Engineers often have special expertise in fields that ordinary citizens do not have
    - ☐ Engineering must comply with applicable laws and regulations
    - ☐ Engineering decisions can impact individuals, communities, and the broader public positively and/or negatively
    - ☐ Employer reputation and profitability depend on the knowledgeable, skillful practices of engineers
    - ☐ Fulfilling such obligations upholds the reputation of the engineering profession

11. Are there any clarifying remarks you would like to make about your answers to the questions in this section?

Section 3

Instructions: this final set of questions seeks demographic and background information.

12. Relevant prior experience: have any of these experiences impacted your answers in this survey? [*Select all that apply*]
    - ☐ Employment as an engineer or engineering intern/co-op
    - ☐ Employment at a for-profit company
    - ☐ Employment at a government agency (federal, state, local)
    - ☐ Employment at a non-profit or non-government agency
    - ☐ Research assistant
    - ☐ Teaching assistant
    - ☐ Work-study student
    - ☐ University-sponsored extracurricular activities
    - ☐ Other (please specify):____
    - ☐ Briefly tell how any of these experiences have impacted your perspective in this survey.

13. Future employment: immediately following graduation, which of the following are you most likely to pursue as your primary position? [*Select one*]
    - ☐ Working for a "traditional" engineering company (at least 50% focus on engineering practice within one engineering discipline)
    - ☐ Working for a multidisciplinary company (no single engineering degree field accounts for 50% or more of the company's activities)
    - ☐ Working for local, state, or federal government
    - ☐ Working for a non-profit or non-governmental organization
    - ☐ Entrepreneur/start your own company
    - ☐ Graduate school in engineering
    - ☐ Graduate or professional school in a field other than engineering
    - ☐ Military service
    - ☐ Other (please specify)____

14. What is your major? [*Select all that apply*]

- ☐ Aerospace Engineering
- ☐ Chemical Engineering
- ☐ Civil Engineering
- ☐ Computer Science
- ☐ Engineering Physics
- ☐ Engineering Plus
- ☐ Electrical Engineering
- ☐ Mechanical Engineering
- ☐ Technology, Arts, and Media
- ☐ Other (please specify)____

15. If you have a minor, please write it here:

____

16. When do you expect to graduate? [*Select one*]

- ☐ 2018
- ☐ 2019
- ☐ 2020
- ☐ 2021
- ☐ 2022
- ☐ 2023
- ☐ 2024

17. From which university do you expect to graduate in the year you selected? [*Select one*]

- ☐ Colorado School of Mines
- ☐ University of Colorado Boulder
- ☐ Other:____
- ☐ Prefer not to answer

18. What is your gender? [*Select all that apply*]

- ☐ Male
- ☐ Female
- ☐ Female-to-Male Transgender
- ☐ Male-to-Female Transgender
- ☐ Non-binary/third gender
- ☐ I prefer to self-describe: ______________________________
- ☐ I prefer not to respond

19. How would you describe yourself? [*Select all that apply*]

- ☐ African American
- ☐ Native American Indian
- ☐ East Asian
- ☐ South Asian
- ☐ Hispanic
- ☐ Native Hawaiian
- ☐ White
- ☐ Multi-racial
- ☐ Other:______________________________
- ☐ I prefer not to respond

20. Are you an international student? [*Select one*]

- ☐ Yes
- ☐ No
- ☐ Other: ______________________________
- ☐ I prefer not to respond

Appendix B: Overall Project Research Questions

The overall research project for which this survey was developed and implemented seeks to answer three research questions:

RQ1. Can the methods used from the investigative team's prior research on sociotechnical integration be transferred to different classes across multiple engineering majors and instructors to support students' development of sociotechnical inquiry methods?

RQ2. Does the teaching of sociotechnical inquiry methods alter engineering students' habits of mind, and, if so, in what ways? We use the AAAS [17] definition of "habits of mind," including the values, attitudes, and skills that they associate with engineering.

RQ3. To support students' development of sociotechnical inquiry methods, can the methods used from the investigative team's prior research on sociotechnical integration be transferred to different classes in different engineering majors and instructors to inform the development of more robust, research-grounded framework that will be used to transfer successful methods to additional courses in engineering?