The Development of Sociotechnical Thinking in Engineering Undergraduates

Kathryn Johnson

Kathryn Johnson is a Professor at the Colorado School of Mines in the Department of Electrical Engineering and is Jointly Appointed at the National Renewable Energy Laboratory. After starting her career with a research focus on wind energy control systems, first developed an interest in engineering education research in the Fall 2011 when she experienced Aalborg University's (Denmark) Problem-Based Learning philosophy. Since then, she has led two NSF grants in social justice and sociotechnical thinking in engineering education. She integrates her research areas in engineering education and wind energy control systems to help students understand the sociotechnical nature of engineering practice in her own technical field (control systems) as well as other electrical and mechanical engineering specialties via collaborations with colleagues at multiple universities.

Stephanie Claussen (Assistant Professor)

Stephanie Claussen is an Assistant Professor in the School of Engineering at San Francisco State University. She previously spent eight years as a Teaching Professor in the Engineering, Design, and Society and the Electrical Engineering Departments at the Colorado School of Mines. She obtained her B.S. in Electrical Engineering from the Massachusetts Institute of Technology and her M.S. and Ph.D. from Stanford University. Her current engineering education research interests include engineering students’ understanding of ethics and social responsibility, sociotechnical education, and assessment of engineering pedagogies.

Jon A. Leydens (Professor)

Dr. Jon A. Leydens is a Professor of Engineering Education Research in the Division of Humanities, Arts, & Social Sciences at the Colorado School of Mines. Dr. Leydens’ research interests are focused on three areas of engineering education: social justice, sustainable community development, and communication.

Jenifer Blacklock (Director of the Western Colorado University Partnership Program)

Dr. Jenifer Blacklock is the Director of the Western Colorado University and CU Boulder partnership program, supporting Mechanical Engineering and Computer Science degree programs.

Barbara M. Moskal (Professor)

Janet Y Tsai (Assistant Teaching Professor)

Janet Y. Tsai is a researcher and teaching faculty in the College of Engineering and Applied Science at the University of Colorado Boulder. Her research focuses on ways to encourage more students, especially women and those from nontraditional demographic groups, to pursue interests in the field of engineering. Janet assists in recruitment and retention efforts locally, nationally, and internationally, hoping to broaden the image of engineering, science, and technology to include new forms of communication and problem solving for emerging grand challenges. A second vein of
Janet's research seeks to identify the social and cultural impacts of technological choices made by engineers in the process of designing and creating new devices and systems. Her work considers the intentional and unintentional consequences of durable structures, products, architectures, and standards in engineering education, to pinpoint areas for transformative change.

**Natalie Plata**
The Development of Sociotechnical Thinking in Engineering Undergraduates

Introduction

Over the course of four years, our team has explored opportunities to bridge the sociotechnical divide between engineering education and engineering practice by examining how sociotechnical thinking emerges and develops in engineering students. In particular, we have explored how we might support changes to engineering classes to illuminate the ways in which engineering is sociotechnical and to make space for learning sociotechnical concepts. The term sociotechnical here refers to the integration of the social and technical dimensions of engineering problems. After graduation, engineering practice and problem solving tends to be increasingly sociotechnical [1], [2], [3]. When considering or solving complex problems, practicing engineers examine both social and technical aspects that are often interlinked (Figure 1). However, Jonassen has argued that the typical U.S. engineering curriculum limits students’ opportunities to develop sociotechnical thinking in an engineering context [4], thereby potentially leaving students ill-prepared for this complex part of their engineering careers.

Figure 1: Engineering practice as a bridge connecting technical and non-technical considerations.

In this project, we have conceptualized sociotechnical thinking as the interplay between relevant social and technical factors in the engineering problem definition and solution process [5]. We consider “social” to be a broad term inclusive of environmental, ethical, economic, health, safety, political, and cultural factors. By “technical,” we primarily refer to decontextualized and/or closed-ended problems that can be solved using mathematical and physical science principles without consideration of the broader social factors and contexts that accompanied the problem definition process or that might be impacted by its solutions. Sociotechnical thinking is closely related to the concepts of macroethics ([6], [7]), social justice ([8], [9]), and Downey’s Problem Definition and Solution (PDS) process [10]. These researchers and others ([11], [12], [13]) have sought opportunities and explored ways to integrate such concepts into engineering courses and curricula, and the research summarized in this paper has built upon this foundation.

Over the course of this project, we have explored the complexities of teaching and learning sociotechnical thinking in three undergraduate classes located in three departments at two universities. Two of the classes are design-focused in the first and second years of engineering curricula and the third is an upper-division engineering science core course (see details in “Courses”). Our mixed-methods study attempted to measure sociotechnical thinking via a survey ([5], [14], [15]). It also used qualitative data from student focus groups, faculty reflection logs
and student work to examine the manner in which sociotechnical thinking influences students’ development of their identities as engineers [16], explored the interconnection between “sociotechnical” and “real world” descriptors [17], assessed the impacts of teaching sociotechnical concepts on faculty [18], and developed a number of course interventions aimed at promoting sociotechnical thinking [19].

Due to the nature of the typical U.S. engineering curriculum, integrating the social with the technical in their classrooms is not a common practice for most engineering faculty. Yet understanding the interplay between the social and the technical is essential for students to succeed in engineering practice ([1], [3], [4]). Through this work, we illustrate how this complex and important area of understanding may be integrated into students’ engineering coursework. This paper and the associated poster summarize the overall project, highlighting both the benefits of and opportunities for sociotechnical integration, mentioning some hurdles we encountered and describing how we overcame them. We invite interested instructors and researchers to join this growing, exciting area of research, addressing sociotechnical reasoning in engineering education.

The remainder of this paper describes the evolution and refinement of the project over four years, including research questions, methods, and courses. It then summarizes key findings from our publications to date and makes recommendations for future research and teaching.

**Evolution of the Project**

Our original proposal sought to answer three key research questions:

**RQ1.** Can the methods used from the investigative team’s prior research on sociotechnical integration be transferred to different classes in two different 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 [20] 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 two different 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?

Although these broad questions motivated and guided our original research study design, formative assessment of our work and the data we collected often led to variations on these questions in our subsequent publications as we explored promising new ideas that arose. For example, RQ1 was a key motivator for our proposal and early work, but the majority of the research was focused on RQ2 and RQ3, which are therefore the focus of this paper. Related to RQ3, staffing changes allowed us to add a third instructor and course in the second semester of the research. It is also noteworthy that our original proposal, from which these RQs are quoted, used the term “sociotechnical inquiry” rather than sociotechnical thinking.
For RQ2, in addition to asking focus group participants specifically about values, attitudes, and skills in alignment with the wording of our original question, we explored new ways of looking at the rich data we collected by adding two additional sub-questions:

RQ2.a. To what degree do the data we have collected show evidence of the definitions of sociotechnical thinking adapted from Downey’s Knowledge Strengths and Limitations and our Sociotechnical Continuum?

RQ2.b. To what degree do the data from the Interview Assignment provide evidence of students demonstrating sociotechnical thinking?

These adaptations to RQ2 were suggested by the preliminary data analysis and our evolving understanding of how students and faculty conceived of sociotechnical thinking. RQ2.b mentions an Interview Assignment for which more information is provided in the “Barriers and Opportunities for Sociotechnical Integration” subsection of the “Summary of the Major Findings” section. For RQ2.a, we adapted Downey’s PDS model from [10]. The three broad categories of knowledge strengths and limitations, diverse knowledge and perspectives, and knowledge and expertise plurality became nodes, with related subnodes for more detailed questions shown in Appendix A. The sociotechnical continuum is our attempt to understand the degree of sociotechnical integration in many quotes from our data. We developed it in two variations, as shown in Figure 2. More information about the codes, attributes, and qualities for the one-dimensional continuum can be found in Appendix A.

![Figure 2: Variations of our sociotechnical continuum. At left, a one-dimensional version with technical-social dualism ([21], [22], [23]) at one end and full integration at the other. At right, a two-dimensional version with separation at the bottom, integration at the top, and a left-right distinction between “technical” and “social” acknowledging that either can be conceptualized to occur separately.]

When relevant, in the “Summary of the Major Findings” section of this paper, additional variations on our research questions addressing new insights that emerged from the data analysis will be included along with the summaries of the papers.

We originally proposed a mixed methods approach in which quantitative data from our survey would provide information about what we observed and qualitative data from a variety of
sources would help us to understand the *why*. The survey was developed as part of this research project and administered in all three classes both at the start and end of each semester in which sociotechnical integration took place with the goal to observe changes in sociotechnical thinking broadly across our student population over the course of a semester. The sources of qualitative data included open-ended questions on the survey, student responses in focus groups, faculty reflection logs, and student assignment submissions. See Appendix B for details of the data collected over the course of the project. Focus groups took place in each intervention section of each class (one or two focus groups per class depending on response rates), student assignments were collected for analysis approximately once per semester per class, and faculty reflection logs were maintained throughout each intervention semester.

Although the surveys led to ASEE conference publications, in general there were few statistically significant results in terms of measurable changes in sociotechnical thinking during an intervention semester, and the majority of the work during the second half of the project has focused on the more fruitful qualitative data from multiple sources. For qualitative analysis, we have most commonly used an inductive analysis method aligned with [24], which in turn draws on grounded theory [25]. This methodology starts with the concrete data and synthesizes it into abstract concepts, often referred to as themes. Figure 3 shows our usual qualitative analysis process. In Phase 1, two or three members of our research team would analyze a qualitative data source – such as a student focus group transcript – through the lens of our research questions. Each individual would write an individual analytic research memo (iARM) grounded in the data. In Phase 2, these team members met one or more times to look for areas of overlap and discrepancy in their iARMs, often returning to the data to resolve questions. Finally, in Phase 3 we reached consensus regarding the themes supported by the data, usually resulting in a consensus analytic research memo (cARM). In phases of analysis where multiple data sources were being analyzed (such as all the focus group transcripts), we would repeat this for each focus group, then use the collection of cARMs to draw conclusions from the set of data sources.

---

*Figure 3: Visualization of typical qualitative analysis process, which starts with individual readings of the data by two or three members of the research team, who write individual analytic research memos (iARM), and ends with a consensus analytic research memo (cARM) synthesizing the data into themes.*
Courses

The three courses we studied were a first-year introduction to engineering course that we call “Projects” that can be taken by students from any major, a second-year introduction to mechanical engineering course (“Intro to ME”), and an engineering science core course required for electrical engineering majors that students typically take in their third or fourth year (“Electromagnetics”). Whereas the Projects course is taught at Institution B, the other two courses are taught at Institution A, as shown in Figure 4.

![Figure 4: Courses by institution, typical year of student enrolled, and type of course (design or engineering science core). Although Electromagnetics is numbered as a third-year course, it is also commonly taken by fourth year students.](image)

Including courses of different types (introduction/design and engineering science core), at different levels, and at different institutions allowed us to better understand the barriers and opportunities across the range of engineering courses, thus supporting RQ3. Information on the data collected in each of the three courses during the first five semesters of the project can be found in Appendix B. All human subjects research protocols were followed at both institutions.

Summary of the Major Findings

Thus far, this project has resulted in seven papers at the American Society of Engineering Education’s Annual Conference and one journal paper (in review), with several more underway. In this section, we summarize the main research questions, methods, and findings in these papers and provide the references for more information. We follow this summary with a synthesizing discussion and recommendations for future work in this promising area for both engineering education researchers and practitioners.

A Survey to Measure Sociotechnical Thinking

The process that we used to develop our survey instrument is described in [5]. The survey was administered at the start (pre survey) and end (post survey) of each semester in which we integrated sociotechnical thinking into our classes. In addition, we administered a couple of pre surveys in non-intervention sections early in the project, and also administered a set of pre and post surveys in non-intervention sections of the Projects class to serve as an additional control (see Appendix B). The goals of the survey were “(1) to quantify student self-reports on their
ability to think sociotechnically, and (2) to measure students’ perspectives on engineering habits of mind and the role of sociotechnical considerations in engineering practice” ([5], p. 5). After developing the survey by drawing from a number of sources in the literature, we requested an expert review from our project’s External Advisory Committee, then conducted a think aloud exercise ([26], [27]) with four volunteer students from our two universities. For each survey question, we asked the students to help us identify points of confusion by explaining what the survey question meant to them in their own words, if there was anything they found confusing, and why they chose the survey answer they selected. The combination of the expert review and think-aloud process resulted in several survey refinements that are described in [5], which also contains the full survey.

We have published results from the survey in [14] and [15]. In [14], we reported a number of differences in the results among the three classes. For example, we combined data from Spring and Fall 2018, then looked at the percentage of students in choosing “Extremely” or “Very” Important in response to the question

“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.

→Identify project-relevant sociocultural issues.” [other options removed for this summary paper]

In terms of course progression by year in school, that percentage declined from 78.7% in the first-year Projects course to 62.2% in the second year Intro to ME course to 59.1% in the third-year Electromagnetics course. This means that students in the Electromagnetics course believed that identifying project-relevant sociocultural issues was less important than students in the other two courses. What was unclear from the survey are the causes of this decline. What role might the engineering curriculum itself have played in forming a “culture of disengagement,” as suggested by [23]? What about the increasing age and intellectual development of the students? Might some of the difference be the populations who self-selected into the Projects course (not all engineering majors), which was also offered at a different university than the Intro to ME and Electromagnetics course?

Finally, we looked to see if there were any gender-related differences in survey responses in [15]. Using unpaired, two-tailed t-tests for a 95% confidence interval with and without Bonferroni corrections, we found a few significant differences on questions that might be considered sociotechnical in nature. For example, students who identified as female ranked the importance of “listening to and integrating the perspectives of both engineers and non-engineers” and “working with people having a diverse set of backgrounds” more highly than male students. (We note that students were not constrained by a binary sex identification in their responses, but an insufficient number of students selected an option other than male or female to make comparisons beyond these two demographic groups.) Further results and explanation of methods can be found in [15].
Barriers and Opportunities for Sociotechnical Integration

In [28], we reported on barriers and opportunities to integrate sociotechnical thinking into our three courses using a collaborative narrative approach. The paper traces the process of creation and implementation of the Interview Assignment including iteration and assessment across multiple semesters. The Interview Assignment required students (or groups of students) to find an engineer and a non-engineer to interview about a specific issue or problem statement. This basic format had many variations for each implementation. For example, in some courses the problem statement was created by the instructors while in other courses the students crafted their own. In some courses students worked alone as interviewers while others did their interviews in teams or pairs. In describing not only the assignment itself, but the surrounding attitudes, obstacles, and insights gained from using the assignment in multiple courses demonstrates the potential for engineering educators’ “Pain and Gain” while performing sociotechnical integration. The specific research questions investigated in this paper were:

1. What are the critical barriers and opportunities to effective sociotechnical integration in undergraduate engineering courses?
2. How do these barriers and opportunities change across different educational contexts, including different institutions, different course content and formats, and different grade levels of students?

Critical barriers included the tendency of the language used in the Interview Assignment to unintentionally further reinforce social/technical dualism rather than socio-technical integration: naming the interviewees engineers/non-engineers or technical/non-technical experts demonstrated how the available terminology is inherently limited. Other barriers identified included choosing an appropriate sociotechnical problem statement to provide to students and the logistical consequences of allowing teams to “divide and conquer” resulting in completed assignments without students directly comparing and actually integrating their interview responses. Yet in analyzing the Interview Assignment’s genesis and iteration, the identified barriers were also mixed with opportunities. For example, creating a single assignment for use across three very different course contexts with multiple instructors and viewpoints was both a challenging barrier and yet an inspiring opportunity for collaboration and growth. Similarly, the demands on instructors’ time and energy to meaningfully teach sociotechnical thinking was a barrier to implementation yet simultaneously an exciting opportunity to demonstrate the feasibility of a single, transferable tool to teach sociotechnical integration across our diverse courses.

Real World Examples

Over the course of the first two years of our project, we frequently heard student focus group statements that “real world” examples overlapped substantially with sociotechnical thinking. This sentiment was also occasionally mentioned when discussing our work with other engineering faculty. Thus, we decided to delve more deeply into the similarities and differences. In [17], we combined theoretical and analytical approaches to explore the overlaps and distinctions between real-world examples and sociotechnical integration in engineering courses. We first proposed characteristics for what constitutes a real-world example vs. more extensive project-based learning or sociotechnical integration for the purposes of our discussion, informed
by how these terms were used in prior research in engineering education. Four key characteristics of sociotechnical integration identified in the paper included that it “must illuminate the complex interplays between people (communities, etc.) and the technical side of engineering,” that it must be explicit, that it must be contextualized, and that it generally relies on open-ended problems ([17], p. 7). We also presented two case studies from the literature of the effective use of real-world examples with and without explicit sociotechnical context. Then, we presented results from the thematic analysis of focus group data which looked at how engineering students discussed the use of real-world examples in their engineering courses and curricula. Finally, we made suggestions for how real-world examples might be modified to include sociotechnical integration. These suggestions include an explicit presentation “with clear and relatable social context, perhaps through stakeholder interviews, readings, in-class discussions, etc.” ([17], p. 19). More details are available in the paper.

Faculty Reflections on Sociotechnical Thinking

Both the study’s original RQ1 and RQ3 require information from the faculty perspective to answer. In [18], we analyzed the faculty reflection log data to explore and understand faculty perspectives on sociotechnical integration in the classroom to support improved integration into courses in the future. As has been argued by Brent and Felder, writing and thinking, as is required for these logs, provokes thoughts and observations that would otherwise be lost [29]. Faculty reflection logs therefore offer a formative tool for deepening instructors’ understanding of their students’ sociotechnical thinking. The paper focuses on the faculty reflection logs for two semesters each of Intro to ME and Electromagnetics (Figure 4), or four total logs. The research question analyzed for the paper was:

1. In what ways do faculty share similar and different insights with respect to the integration of sociotechnical thinking within their engineering classes as reflected through faculty reflection logs?

To answer this research question, we used inductive analysis [24] and the process shown in Figure 3. For this analysis, the team used open coding of each of the four faculty reflection logs (FRL), where each co-author wrote an individual analytical research member for each FRL. Teams met to create a consensus analytical research memo (cARM) considering both agreement and disagreement. All findings were traced back to quotes in the initial data. From this analysis, two major themes emerged, each of which contain subthemes described in [18]:

Theme 1: The relationship of motivation, engagement, and receptivity to sociotechnical integration
Theme 2: Successful techniques for sociotechnical integration in the class

From this analysis, we learned more about successful integration of sociotechnical thinking into technical courses through the integration of real world, open-ended concepts into the course content to promote engagement and motivation. We also learned that microinsertions integrated throughout the semester along with creating simple questions like “Who benefits? Who suffers? Who is not ‘at the table’?” can be added to technical discussions easily and are a successful way for sociotechnical integration into courses. Finally, from a faculty perspective, it was found that
creating a support community with colleagues who have similar sociotechnical motivations is important for sharing ideas and gaining support when teaching these topics.

**Intersection of Engineering Identity and Sociotechnical Thinking**

Analysis of our focus groups made us aware of the myriad connections that our focus group participants were making between their engineering identities and their perceptions of sociotechnical thinking. As an initial investigation of these connections, we used narrative analysis to look at how individuals in five focus groups related their engineering identities to sociotechnical thinking [16]. This first paper led to a follow-on analysis which looked specifically at liminal engineering identities – instances where students both did and did not identify as engineers, or where they stated that they did “not yet” identify as an engineer. Our analysis identified six categories that collectively describe the explanations students give for their liminal identities. These results have been described in a draft journal paper that is under review [30].

**Discussion and Recommendations**

**Research**

Many opportunities remain for research, both within our existing data and for future studies founded in our findings. For example, although we have completed detailed analyses based on most of our individual data sources and combined some, many further opportunities exist in various combinations of our data types, as illustrated in Figure 5.

![Figure 5: Opportunities for cross-data analysis, combining findings from multiple data sources. Combining the faculty data source (faculty reflection logs) with student data seems especially promising based on preliminary analysis.](image)

For example, we developed the questions listed in Table 1 drawing from multiple data sources at a brainstorming session related to fruitful next steps in our research.
<table>
<thead>
<tr>
<th>Question</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the range of student responses to sociotechnical engineering? Which kinds of students thrive, benefit, suffer, and/or are distracted by the integration of sociotechnical engineering? What seems to motivate that response? What might instructors do to productively address (or prevent) that range of responses?</td>
<td>✅</td>
</tr>
<tr>
<td>“I wish it wasn’t this way”: What differences exist between how students perceive that engineering works and how they wish it worked?</td>
<td>✅</td>
</tr>
<tr>
<td>Given what we have learned from the qualitative analysis of the other data sources, how would we revise the survey to make sure it is measuring what we want it to measure?</td>
<td>✅</td>
</tr>
<tr>
<td>In integrating sociotechnical engineering, where is the pain and gain for instructors? Which kinds of instructor mindsets are antithetical to such integration? Which mindsets appear to align well? How does traditional training in engineering education (as an undergrad., grad. student, faculty member, etc.) shape such mindsets?</td>
<td>✅</td>
</tr>
<tr>
<td>How do students and faculty conceptualize sociotechnical engineering? If those conceptualizations align, how? If they diverge, how?</td>
<td>✅</td>
</tr>
<tr>
<td>What criteria or qualities best characterize technical-social dualism vs sociotechnical integration? Do the data suggest intermediate levels such as the partial integration shown in Figure 2?</td>
<td>✅</td>
</tr>
</tbody>
</table>

In other words, Table 1 suggests opportunities that preliminary work suggests may be quite promising. First, we have observed differences among students in terms of who appears to value sociotechnical thinking more or less and believe there may be opportunities in the data to better understand how to reach students from underrepresented groups. Second, we have observed through our work on students’ liminal engineering identities that there may be disconnects between what students think engineering is vs. what they wish it could be, and believe that further work to understand the overlap of data from students and faculty can suggest a richer description of each that could inform teaching and learning. Third, we believe that the qualitative
data offers some explanations related to our survey results that could be used to create an improved instrument in the future. Fourth, we observed both barriers and opportunities for faculty that might benefit from an improved understanding of the ways in which students perceive sociotechnical integration compared to faculty. Finally, we believe that the meaning, conceptualizations, qualities, and attributes of sociotechnical thinking could be better described by carefully integrating student and faculty perspectives.

Classroom

In terms of in-class sociotechnical interventions, we found success in the following ways. First, illuminating relevant problems that have been solved in non-technical ways has helped our students (and colleagues) to think about redefining “engineering” problems to allow different ways of thinking about solutions. The “Dutch reach” example to reduce driver-bicyclist collisions in the Netherlands is one example [31]. In the Projects course, students were prompted with the scenario and asked to think about how to prevent these collisions for a roadway configured as in Figure 6. Not surprisingly for students in an engineering class, many came up with ideas related to sensors and alarms to alert a driver when a bicyclist is nearby. When told that good results ensued from teaching drivers to open the door with their right arms (the so-called “Dutch reach,” which causes their bodies and eyes to turn towards the roadway and makes it easier to see on-coming cyclists), many expressed surprise. A key lesson from this experience was not to provide the solution up front, but rather to first ask students to come up with their own solution, then discuss why their solutions may have disregarded behavioral possibilities, which can help to illuminate mindsets in engineering. The instructor then found it helpful to discuss how the “social” solution as a launching point to discuss the impact of the problem definition on the available solution space.

![Figure 6: Illustration of roadway with parked cars outside of bike lanes that is used for the Dutch Reach example. In this example, the problem of drivers opening car doors into cyclists is solved behaviorally rather than technologically.](image)

In our Intro to ME class, one method for sociotechnical integration was via universal design, which is a tool for inclusive design practices. Although not directly sociotechnical, universal design is a tool that prompts people to think about different kinds of user and/or stakeholder needs. It can be used as a stepping stone toward sociotechnical thinking, especially when it forces students to get “out of the building” (where the building often consists of engineering
students and faculty with similar life experiences and backgrounds, thereby failing to illuminate different ways of thinking and knowing).

In our Electromagnetics class, we found success using “microinsertions,” small but frequent integration of sociotechnical thinking into existing class topics (Figure 7). For example, students were prompted to discuss who benefits, who may be harmed, and who may be left out of the design and development of technologies such as the lab-on-a-chip and solar cells. For these conversations to be more successful, we found it necessary to introduce sociotechnical thinking prior to the conversation, for example by using the Dutch Reach and similar examples. In other words, students were better able to think sociotechnically when given concrete examples than when asked to think more abstractly.

![Figure 7: Illustration showing microinsertions (white diamonds) interspersed within major course topics (large color bars). Without taking a substantial amount of time, repeatedly returning to a few key sociotechnical questions can be a powerful learning tool.](image)

We have also discovered that it is critical to integrate sociotechnical thinking into the problem definition phase instead of only the solution phase since engineering “problem statements” often artificially constrain the problem space, limiting the possibility for deep sociotechnical thinking, as illustrated in Figure 8.

![Figure 8: Illustration of how expanding the problem definition space (green trapezoid in right image compared to blue trapezoid in left) can therefore expand the available problem solution space (yellow rectangles). Sociotechnical thinking is not explicitly shown but is intended to be part of the expanded space.](image)

As mentioned in the summary of our “Barriers and Opportunities” paper [28], we developed an Interview Assignment that is designed to be useable across a range of engineering courses and that is focused on problem re-definition in ways that can highlight different mindsets held in engineering and other fields. This assignment is available to all at our project website [19] and we welcome feedback from other interested faculty who wish to try it in their classes. Although
we found this assignment to be an effective teaching tool in our classes, we are aware that there are always opportunities to improve.

A substantial hurdle identified by faculty, students, and participants at our project workshops was how to grade sociotechnical elements of the courses. We note that the stakes are higher when sociotechnical thinking is integrated into the syllabus or course deliverables. Rubrics carefully designed to assess sociotechnical learning objectives can help address this issue; we offer one example related to the Interview Assignment at our project website [19]. Another approach is to offer credit for completion of sociotechnical elements or to do a quick assessment of depth and thoughtfulness, for example assigning 50% credit for the content of submissions and 50% for clarity and depth of explanations.

Finally, we emphasize the importance of finding a community of like-minded researchers and teachers. Especially for the many of us who were taught in more traditional engineering programs, it is easy to suffer from the imposter syndrome when trying to integrate complex topics like sociotechnical thinking into our classes, believing we do not have the skills required or the time to learn them. Our team is excited to discuss the possibilities that these pedagogies present with other interested faculty.

More examples related to teaching sociotechnical integration, including two workshops we conducted for interested faculty, are also available at our project website [19].

Conclusions

In conclusion, we believe that our accomplishments in this project have illuminated a wealth of opportunities for both the research and teaching of sociotechnical thinking in engineering education. In this paper, we have summarized our major findings, referring to our relevant publications and resources, and highlighted key questions and opportunities for future exploration. These major findings include indications of some gender-based differences in how students value sociotechnical engineering, both barriers and opportunities to sociotechnical integration in our classrooms, the fact that oft-prized “real-world” examples are not necessarily sociotechnical, and some understanding of the intersections between liminal identity and sociotechnical integration. Key questions include whether there are better ways to measure sociotechnical thinking, especially ones that might illuminate demographic differences potentially impacting diversity and inclusion; whether our insights into “real-world” problems can be used to improve future integration and teaching; and how students’ liminal identities are shaped in both traditional and sociotechnical engineering education settings. We believe sociotechnical integration is an important topic for the future of engineering education because of its potential to improve engineering practice as well as potential implications for diversity and inclusion at both the student and faculty level. We continue to analyze the very rich data we were able to collect and plan more publications in the future. For example, we are currently exploring what the diverse student perspectives on sociotechnical thinking observed in our focus groups tells about what engineering educators should do, accentuate, or avoid when trying to teach to that range of perspectives. We would be excited to discuss opportunities for future work on sociotechnical thinking with other interested researchers and teachers.
Acknowledgments

This material draws from work supported by the National Science Foundation under Grant No. EEC-1664242 within the Research in the Formation of Engineers program. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors also wish to thank the other researchers who have been part of our team over the course of the project: Alyssa Boll, Randy Cook, Olivia Cordova, Brandon Dickerson, Colin Endsley, and Jackie Erickson.

References


### Appendix A: Codebooks for our Sociotechnical Continuum (Figure 2) and Downey’s Problem Definition and Solution (PDS) Model

#### Sociotechnical Continuum

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sociotechnical integration</strong></td>
<td>Original codes: “Sociotechnical problem defining, solving, mutually shaping dynamics.” Attributes: “In both problem defining and solving, the complex and potential interplays between social and technical dimensions are acknowledged and accounted and/or planned for.” Qualities: “when asked how social elements inform engineering problems or solutions students may, for example, indicate how stakeholder input informed the problem definition and design engineering solutions that benefit both clients and disenfranchised stakeholders.”</td>
</tr>
<tr>
<td><strong>Partial integration-separation</strong></td>
<td>Original codes: “Technical separation and sociotechnical integration.” Attributes: “Only a few readily quantifiable social dimensions are accounted for; others are minimized or not engaged. Or, a few crucial sociotechnical intersections are stipulated, while others are not.” Qualities: “when asked how social elements inform engineering problems or solutions students may, for example, list safety considerations for individuals interacting directly with the technology, but not explore more complex sociotechnical interplays.”</td>
</tr>
<tr>
<td><strong>Technical-social dualism</strong></td>
<td>Original codes: “Technical expertise, technical problem definition and solution processes.” Attributes: “The technical and the social dimensions are conceptualized as separate; interfaces between the technical and the social dimensions of engineering problems are rare or nonexistent.” Qualities: “when asked how social elements inform engineering problems or solutions students may, for example, express surprise, be unable to think of an answer, or indicate that they see engineering as a technical discipline largely devoid of any relevant social issues.”</td>
</tr>
</tbody>
</table>
### Codes Adapted from Downey's PDS Model

<table>
<thead>
<tr>
<th>Code, Subcodes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diverse knowledge and perspectives</strong></td>
<td>Example: [Source: FG01-Fall 2018, Projects] Victoria: 16:10 Yeah. Especially I think with the way our class is oriented some of us have experience in a projects type environment ... at least of some of us, we've done this before over the summer and- Becca: 16:28 Or in classes in high school. Victoria: 16:29 Yeah, or in classes in high school. A lot of us have some form of experience where some people in the group have no experience and I feel like they won't get as much out of it I guess in some sense. So, I feel like the strength test really was identifying who's had this experience and who's gonna do ... It almost identifies who's gonna do the majority of the project vs. who's just kind of sitting there and listening and trying to learn type of thing.</td>
</tr>
<tr>
<td>Project-relevant socio-cultural issues</td>
<td>To what degree are project-relevant socio-cultural issues identified and used for practical reasoning?</td>
</tr>
<tr>
<td>Working with people who define problems differently</td>
<td>To what degree do students demonstrate understanding of the importance of learning to work with people who define problems differently than they do?</td>
</tr>
<tr>
<td><strong>Knowledge expertise and plurality</strong></td>
<td>[Source: FG01-Fall 2018, Projects] Becca: And that doesn't normally fit with engineering. So sometimes I'll look at things from fairy tales point of view. I'm taking a class on that right now and so that's completely different from looking at it from an engineering point of view. Becca: 23:22 What my parents tell me a lot is I'm gonna be the person who's gonna be able to tell the non-engineers what the engineers are thinking. So, I can easily translate the technical language to language that everybody else can understand.</td>
</tr>
<tr>
<td>Legitimize human dimensions of engineering</td>
<td>To what degree do students render visible and legitimize “the human dimensions of engineering work alongside technical problem solving?” ([10], p. 594)</td>
</tr>
<tr>
<td>Mediate between engineers and non-engineers</td>
<td>To what degree are students able to “function effectively as mediators among different types of engineering specialists” and non-engineers?</td>
</tr>
<tr>
<td><strong>Knowledge strengths and limitations</strong></td>
<td>Example: [Source: FG01-Fall 2018, Projects] Katie: 37:25 So how did your projects instructor convey the concept of socio-technical engineering? Katsa: 37:33 She kind of gave a presentation about it and lectured about ... she gave a lot of examples of when things went wrong and then told us, just talked about unintended consequences and what they could've thought of to make their product better. Katsa: 37:54 She just gave us examples like different material that people used and how it affects the earth, or how different perspectives might be need to be taken into account in order to make something that's actually useful or a wide-range that people could use.</td>
</tr>
</tbody>
</table>
Acknowledge Knowledge
Strengths and Weaknesses
To what degree do students acknowledge the strengths and limitations of different forms of knowledge for solving diverse kinds of problems?

Recognizing Ambiguity
To what degree do students recognize ambiguity and uncertainty, and what do they do when they encounter those issues?

Using Tech and Non-tech knowledge
To what degree do students identify and use both technical and non-technical bodies of knowledge?

Appendix B: Data Collected

Data collected in each of the three courses by term. Some sections were non-intervention due to changing teaching assignments for the project team. Acronyms: FG = focus group, FRL = faculty reflection log, and IA = interview assignment. Note that “non-intervention” sections were used to prepare for the research or were taught by faculty other than our research team.

<table>
<thead>
<tr>
<th>Term</th>
<th>Projects</th>
<th>Intro to ME</th>
<th>Electromagnetics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2018</td>
<td>(non-intervention)</td>
<td>(non-intervention; course not yet part of the study)</td>
<td>(non-intervention)</td>
</tr>
<tr>
<td></td>
<td>▪ pre survey</td>
<td></td>
<td>▪ pre survey (N=148)</td>
</tr>
<tr>
<td>Fall 2018</td>
<td>▪ pre and post survey (N=21, 32)</td>
<td>(non-intervention)</td>
<td>(non-intervention)</td>
</tr>
<tr>
<td></td>
<td>▪ 2 focus groups</td>
<td>▪ pre survey (N=148)</td>
<td>▪ pre survey (N=14)</td>
</tr>
<tr>
<td></td>
<td>▪ FRL</td>
<td></td>
<td>▪ pre survey</td>
</tr>
<tr>
<td></td>
<td>▪ IA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring 2019</td>
<td>(non-intervention)</td>
<td>▪ Pre survey (N = 128)</td>
<td>▪ Pre and post survey (N = 6, 35)</td>
</tr>
<tr>
<td></td>
<td>▪ Pre and post survey (N = 94, 94)</td>
<td>▪ IA</td>
<td>▪ IA</td>
</tr>
<tr>
<td></td>
<td>▪ 2 FGs</td>
<td>▪ 2 FGs</td>
<td>▪ 2 FGs</td>
</tr>
<tr>
<td></td>
<td>▪ FRL</td>
<td>▪ FRL</td>
<td>▪ FRL</td>
</tr>
<tr>
<td>Fall 2019</td>
<td>▪ Pre and post survey (intervention N = 28, 28; non-intervention N = 127, 127)</td>
<td>▪ Pre and post survey (N = 121, 104; ~50% in intervention section)</td>
<td>▪ Pre and post survey (N = 26, 28)</td>
</tr>
<tr>
<td></td>
<td>▪ IA</td>
<td>▪ IA</td>
<td>▪ IA</td>
</tr>
<tr>
<td></td>
<td>▪ 1 FG</td>
<td>▪ 1 FG</td>
<td>▪ Student reflections on IA (N=5)</td>
</tr>
<tr>
<td></td>
<td>▪ FRL</td>
<td>▪ FRL</td>
<td>▪ 1 FG</td>
</tr>
<tr>
<td>Spring 2020</td>
<td>(non-intervention; no data collection)</td>
<td>(non-intervention; no data collection)</td>
<td>▪ Pre and post survey (N = 52, 40)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>▪ IA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>▪ 2 FGs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>▪ FRL</td>
</tr>
</tbody>
</table>