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Sociotechnical Integration: What Is It? Why Do We Need It? How Do We Do It?

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Sociotechnical Integration in Engineering:
What is it? Why do we need it? How do we do it?

Abstract

Sociotechnical integration is an innovative, yet arguably elusive, approach to engineering education. It acknowledges how the bounds of technical and nontechnical knowledge are blurred and makes space for generative work at their intersection. Traditional engineering coursework tends to promote narrowly defined conceptions of "engineering knowledge" as exclusively technical. Sociotechnical integration encourages engineering educators to explore the space connecting technical and nontechnical disciplinary silos. We believe this connection can be more than a middle ground or a hybridization of the disciplines, but rather a bridge to new potentials for engineering education. This paper draws on relevant scholarship and empirical insights from a set of interviews with select engineering educators to interrogate the practice and potential of sociotechnical integration. Interviewees represent a wide range of academic positions, disciplinary backgrounds, and educational programs and were selected for this study to provide a broad set of perspectives on creating and leading engineering programs that systematically engage the social. We explore the motivations underlying sociotechnical approaches, the goals we hope such approaches will achieve, and the mechanisms used to integrate social content into engineering classrooms and programs. In so doing, we build on the work of our colleagues who highlight distinct frameworks for "sociotechnical" engagements, entailing different modes of defining the categories of "social" and "technical" and conceptualizing their relationship. Such distinctions are useful because, despite the depth of commitment to sociotechnical integration among our selected interviewees, their approaches vary considerably. In light of our findings, we have developed our own approach to sociotechnical integration for our institutional context, which we share in closing. Taken together, we believe this work can aid readers in exploring the current status and potential futures of sociotechnical integration in engineering education.

Introduction

This paper explores sociotechnical education as an antidote to the narrow technical specialization typical of most contemporary engineering education. Sociotechnical frameworks for understanding engineering practice have been common in science and technology studies (STS) for decades [1] and are increasingly found in discussions within engineering education spaces [2, 3, 4, 5]. In fact, sociotechnical approaches to engineering education are even being adopted by disciplinary engineering faculty in traditional technical engineering courses, often through collaborative initiatives driven by faculty with training in or exposure to STS [6, 7]. This work is widely reported through scholarly venues such as ASEE's Liberal Education/ Engineering and Society Division; the Society for Social Studies of Science (4S) conference; and the Engineering, Social Justice, and Peace conference. Some undergraduate engineering programs are even going further, making sociotechnical frameworks a key feature of their programs' course offerings and educational outcomes [8, 9].

As engineering educators and science and technology studies (STS) scholars, we are particularly interested in modes of teaching engineering built on *sociotechnical integration*. Sociotechnical integration takes seriously both social and technical dimensions of engineering practice without conceptually privileging either. We use the term "integration" to mean both a practice of continual, fluid iteration between social and technical dimensions of engineering decision making and a conceptual commitment to refuse to treat "social" and "technical" as distinct facets of engineering practice. Our efforts to understand sociotechnical integration and its implications for engineering education are motivated by both our scholarship and our educational program building.

Sociotechnical approaches to the teaching of engineering have been promoted as a mechanism to achieve a variety of far-reaching educational and social benefits, including:

- diversifying engineering,
- enhancing student engagement in the classroom,
- addressing ABET learning-outcomes surrounding the understanding of "context,"
- supporting students' ability to engage ambiguous, open-ended problems with attention to diverse stakeholders,
- creating more reflexive and ethical engineers, and
- preparing engineers to collaborate better across disciplinary and cultural differences.

Interest in these promises often derives from sociopolitical critiques of engineering, which respond to engineering's close alignment with contemporary configurations of capital and militarism [10, 11, 12], interrogate the distribution of agency and responsibility within engineering [13, 14], and produce engineering educational spaces that can reproduce inequities while purportedly operating as "unbiased," "apolitical," and "rigorous" [15]—all while animated by particular environmental, social, and technical conditions constraining the world in which engineers hope to intervene [16]. Our efforts to advance pedagogies and programing founded on sociotechnical integration arise against this backdrop of sociopolitical critique.

Our work supports a growing movement of sociotechnical integration by comparing insights from some of its leading educators and highlighting the diversity in their interventions in terms of motivations, pedagogies, and institutionalization efforts. This diversity results from a combination of choices related to specific moments in institutional and social history, organizational opportunity, and chance. The result: while many thoughtful educators are deeply invested in the promise of sociotechnical integration in engineering, their approaches vary considerably.

In light of our findings, we have developed an approach to sociotechnical integration for our own institution. This involves a series of workshops to help faculty build a common language and set educational practices to achieve what we hope is an especially robust form of sociotechnical integration. This robust integration is to be achieved through a 3-step process: 1) grappling systematically and iteratively with the social and technical dimensions of a given engineering design tool, as understood by traditionally trained engineers, design educators, and STS scholars; 2) creating a common language to describe how the social and technical dimensions of the tool are, in fact, mutually constituted; and then 3) devising educational activities to convey that mutual constitution of the social and technical dimensions of the tool at the same time as students are taught how to use the tool.

Conceptual Foundations

One recent touchpoint for STS scholars working on social integration in engineering education is Gary Downey and Teun Zuiderent-Jerak's [17] framework for "activating STS sensibilities" beyond the field. For us, this "activation" is grounded in a theoretical understanding of how dimensions of engineering commonly recognized as (exclusively) social or (exclusively) technical are in fact intertwined, so much so that any boundaries between the two can appear arbitrary [18, 19, 20]. Our activation is indelibly practical as well as theoretical. We draw on these theoretical findings to support and develop "engineering-plus" coursework in our engineering school to support goals that range from integration of humanities and social sciences content to professional development to advancing business acumen. We aspire to go beyond such approaches to achieve more robust and consistent integration of technical and social dimensions of engineering across the entire arc of our engineering students' educational experience.

Smith et al. [21] provide a concrete starting point for exploring conceptualizations of social and technical intersections in engineering. They note that educators use the term "sociotechnical" in a variety of ways, including to refer to engineering itself, as well as "habits of thinking," "mindsets," and "abilities," or simply as a means to recognize a wider range of "relevant factors" impinging on engineering outcomes. Drawing on these definitions; observations of student knowledges, skills, and attitudes; and relevant scholarship, Smith et al. provide a useful typology for identifying distinct underlying conceptions of sociotechnical integration held by engineering educators.

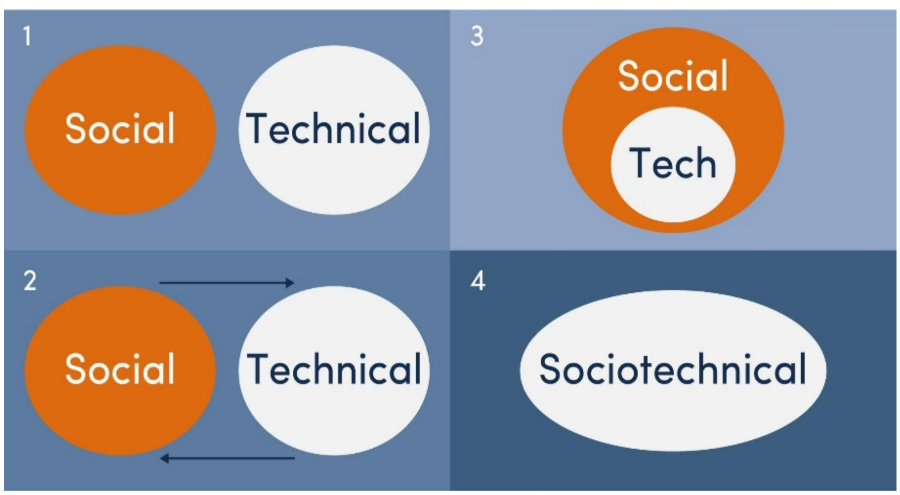

Figure 1: Four approaches to sociotechnical analysis. Adapted from Smith et al. [19]

We mobilize this typology by labeling and elaborating each of the four categories as well as highlighting the implicit progression of conceptual nuance across the categories. In the most general terms, this typology conveys increasing degrees of conceptual integration between social and technical dimensions of engineering (or of any other domain of human practice).

1. **Independence**: The social and technical dimensions of the phenomenon are each important but distinct. They can be treated separately or together in parallel, but there is no necessary correspondence.

2. **Mutual shaping**: Social and technical dimensions of a phenomenon are conceptually distinct but impact one another in an endless cycle of influence. One can isolate a given social or technical dimension at a given point in time, but must recognize the particular configuration has been shaped by both social and technical antecedents.
3. **Pervasive social context**: Technical dimensions of a given phenomenon and technical knowledge itself are always situated within the pervasive social context of human activity, human infrastructures, and human understanding.
4. **Sociotechnical integration**: Social and technical dimensions of a given phenomenon are not only mutually shaped, but are fully mutually constituted: One cannot exist without the other, conceptually or materially. Independent constructs of social and technical are misleading simplifications, since each is necessarily and inexorably intertwined with the other.

This framework supports our conceptual understanding of different ways that sociotechnical engineering education might be undertaken. This framework helps us understand the diversity of ways thinkers and practitioners in this field understand the interplay between engineering's "social" and "technical" dimensions.

Empirical Foundations

To help advance our efforts in sociotechnical integration, the authors interviewed domain experts who lead efforts bringing "social" content and context into engineering education. Our research pool consisted of engineering educators with decades of experience teaching the social and human dimensions of engineering, developing and leading relevant academic programs relating to social dimensions of engineering, and serving in a variety of academic leadership roles, typically predominantly or exclusively within engineering or STEM programs, colleges, or universities. Their educational credentials spanned technical engineering disciplines, engineering policy, STS, sociology, anthropology, and communications. One of our interviewees was a junior scholar (and part of a junior-senior scholar team), but the remaining eight all had 20+ years of experience teaching engineers and STEM students. The two interviewees with technical engineering doctoral degrees have each engaged with the social dimensions of engineering for well over 20 years. Our interviewees would all be widely known among members of ASEE's Liberal Education/Engineering and Society Division for their scholarship and educational program development activities.

We conducted 90-minute, semi-structured interviews with these nine engineering educators. These experts were selected via purposive sampling, which considered their scholarly standing and programmatic leadership advancing sociotechnical approaches to undergraduate engineering education across the United States, the United Kingdom, and Canada. Through these interviews, we sought to identify:

- Motivations for focusing on social integration,
- Goals social integration was intended to achieve, and
- Approaches to integration and the mechanisms by which that integration was achieved.

Interviews covered a variety of topics related to motivations for, scholarship on, and practice surrounding sociotechnical integration initiatives. We sought to identify opportunities and barriers along various dimensions: conceptual (e.g., underlying theoretical foundations, scholarly referents); practical and logistical (e.g., time requirements, curricular opportunities); and institutional (e.g., alignment with promotion requirements, opportunities for co-instruction). The interviewees mostly focused on the variety of educational initiatives they were currently involved in, including courses and curricular undertakings, co- and extra-curricular activities, participation on institutional-change efforts, and research activities, including major grant-funded educational interventions.

Findings: Underlying Motivations, Goals, Mechanisms, and Institutional Constraints

Our interviews covered four general dimensions of engagement with social integration into engineering education, focusing on the underlying motivations propelling the work, the specific goals the integration was aspired to achieve, the mechanisms for achieving integration, and institutional constraints to their work. We attribute quotations where interviewees requested and leave unattributed quotations from interviewees who preferred to remain anonymous for this study.

Underlying Motivations: Why pursue sociotechnical integration?

We started our interviews by discussing approaches to integrating "social" perspectives into engineering education, hoping to characterize our interviewees' approaches to sociotechnical integration. However, our interviewees described underlying motivations that varied tremendously. For example, one interviewee sought to activate students' learning by exposing them to multiple lenses and …. [to] recognize the limits of their own expertise as well as the value of other people's expertise." The interviewee described this approach as a form of "systems thinking and analysis."

Several interviewees pursued sociotechnical integration to broaden participation in engineering. For example, one interviewee connected sociotechnical integration to her engineering institution's core commitment to diversify engineering:

> So we're going to use a nontraditional admissions process to hopefully broaden the pool of people who would be attracted to engineering. The big institutional context is to expand the diversity of people who could become engineers by talking about engineering differently, and doing engineering differently.

Another interviewee made a similar connection:

> For me, [social science perspectives provide] a way to make engineering more inclusive, and I see this [development as freedom] project as a part of that: … allowing students to develop their own sense of where they want to go by helping to support students along unconventional paths in engineering. I see that as being really central to the project of inclusion and allowing students to bring their whole selves to the class and recognizing talents that are sort of outside the traditional engineering skill set.

A few of our interviewees articulated a deeply personal approach to exploring what sociotechnical integration could mean. Linda Vannasupa of Olin College shared, "I'm on a life's journey ... for myself be integrated." Donna Riley of Purdue University told us, "I probably have had different stakes at different points in my life." A third interviewee articulated his motivation like this:

> I think I've come to realize that individual freedom is really central to this question…. It's based on Amartya Sen's *Development as Freedom* framework, where he sees the promotion of freedom as central to all forms of development…. I think engineering just completely misses its role in creating, through technology, a future that allows new ways of being in the world.

For these three engineering educators, among others, sociotechnical integration was deeply personal, but also deeply time- and context-specific. Indeed, many people we interviewed noted divergences between different efforts for sociotechnical integration that they were engaged in. As one told us, some of the work she was involved in was "more aligned with my personal definition of what it means to be integrative" than other work.

Goals to Be Achieved: What does sociotechnical integration get us?

Despite their varied motivations for social integration, interviewees recounted overlapping promises that were bold and compelling. In our interviews, it was common for them to describe the wide-ranging skillsets that engineers tended to be deficient with and that sociotechnical integration address. An interviewee put it this way:

> I think about the kinds of things that I hope they will have learned, absorbed, considered, experienced as they learn to become an engineer…. For me personally, that includes much more of the liberal arts and humanities, … especially in the communication and ethics fields specifically…. It's beginning to seem more natural [that] history and sociology and politics and ethics [are] considerations that engineers might have to adopt in their practice.

It was also common for them to focus on engineers' impact on the broader world, including their ability to address enduring, systemic challenges. The educator quoted above whose institutional mission was to broaden participation in engineering not only linked sociotechnical integration with broadening participation, but also identified both of these elements as prerequisites for addressing complex global challenges.

> Not only do we need to solve, you know, our own local problems, but [we focus on sociotechnical integration] because of the belief that only by educating engineers differently can we begin to grapple with some of the complex global challenges. Those will require an integrated approach in order to solve and so we best start educating engineers with an integrated approach.

In fact, multiple interviewees articulated a vision of engineering that was sharply focused on social impact, justifying sociotechnical integration as a means of reorienting engineering toward more positive impacts. One interviewee suggested sociotechnical integration was needed as an antidote to increasing disciplinary fragmentation: "We keep splitting off new disciplines, new areas of study, but there's no course of convergence that brings us back together to solve important societal problems." Another interviewee reflected on the range of perspectives that need to be integrated, putting it this way:

> If we're going to have engineers who are trying to make a positive impact on the world, and understand sociotechnical problems and the context in which they're trying to work, they need to

> understand society and power and history and beauty and art and what really matters to people. All sorts of things like that. And they won't get that with a narrow disciplinary perspective.

Interviewees not only indicated that sociotechnical integration could develop students' skillsets and impact on the world, but also could transform their very ways of being. For example, one interviewee said the goal was not just to make "a better engineer [but] a better person." Another described sociotechnical integration as something that might not *change* students as much as allow them to bring skills and perspectives that they already had outside of the classroom into it: Students could "develop their own sense of where they want to go by helping to support [them] along the unconventional paths in engineering." This approach was seen as "central to the project of inclusion and allowing students to bring their whole selves to the class."

While all of those we interviewed saw substantial opportunities for integrating concepts generally considered "social" into the technical work of engineering, Jane Lehr of California Polytechnic State University offered a caution against what she termed "the super engineer." Lehr asserted that all the promises surrounding sociotechnical integration could create undesired consequences if they "were expanding what counts as engineering expertise, but doing so in a way that still absolutely privilege[d] the … engineer as the knower [who] does not invite collaboration." Lehr advocated for educating engineers to be expansive in their engagement with the social dimensions of engineering while simultaneously recognizing the limits of their expertise and the need to involve others in the problem-solving process.

<u>Mechanisms: How to achieve sociotechnical integration education?</u>

Across our interviews, we identified two common mechanisms described for integrated social dimensions of engineering into students' educational experience: 1) layering of "the social" as a key but largely absent category within engineering education and 2) integration of social and technical expertise via co-instruction, often in the context of design projects.

Layering

Many educators frame sociotechnical integration as bringing social perspectives to engineering students, in a wide variety of ways, where the "integration" is achieved by adding it to students' educational experience in a way that is considered directly relevant or directly applicable to the students' perceived priorities, say around advanced technology development, social dimensions of technology, or technology's social and historical contexts. One interviewee suggested an effective lever for such integration was "systems thinking":

> Our design courses where we are able to have students understand the context of the engineering work they're doing—the social context, the political context, the economic context, you know. There are all these contexts that we sort of give lip service to in engineering. But we're having students actually develop representations of those contexts and use representations in their thinking, and so I would say that systems thinking would be a really good place to integrate the social sciences with engineering.

This interviewee went on to describe how his institution's approach to design education aligned closely with his views on the need to layer diverse analytic perspectives:

> You know, design [requires] learning more about the social sciences. It's not that there is a single lens that you use, but there are a variety of lenses, … a set of lenses that students can adopt … to look at

> different facets of a design problem. [W]e have eight facets. [T]he model we're using across all our design courses [includes] a lens of value, a lens of people, a lens of context, a lens of function, a lens of design, which is really the process, the lens of integration, a lens of performance, and a lens of communication. [We] represent the project through all eight of those lenses, so students get sort of a multi-faceted view of their project. It's not just a narrow "Let's complete this technical thing."

In terms of addressing social context, special attention is often paid to social power relations surrounding decision making and their implications for inequitable outcomes related to technologies. This approach is typically operationalized via relevant courses that are interspersed—and exist in parallel—with students' more "technical" engineering coursework.

One interviewee connected the core skillset of understanding social context and social power as requirements for positive social impact.

> I think about power all the time, and equity issues… Our graduates really need to be able to [think like this]. They're not going to be able to make a positive difference in the world if they have really narrow perspectives of what it means to be an engineer and what it takes to be an engineer. And so I think that for undergraduate engineering education, we have to [help them identify their position in the larger society].

In some institutions, courses on social issues related to technology can be assembled into minors or other programmatic configurations intended to supplement students' primary engineering degree. One interviewee who formerly served as director of such programming reflected on the institutional challenges of this approach, notably including how such programming often fails to "count" for students—either misaligning with institutional "core" breadth requirements or failing to count as engineering electives.

Layering the social as a core category within engineering education is arguably the dominant approach to teaching engineering students across the liberal arts, including the wide variety of STS-type courses that explore the social dimensions of a variety of specific science and technology domains, such as "technology and society" or "engineering ethics." While we value and participate in such instructional approaches, and while we see the inevitability of and institutional appetite for them, we also note that this set of educational practices typically does not deeply engage the "technical" content of engineering education in ways that would be legible to technical engineering educators. In other words, these approaches might be characterized as *about* engineering (sometimes including its technical content) but not incorporate "engineering" content itself.

Co-instruction

One common mechanism for achieving an integrative approach is co-instruction between an instructor trained primarily in "the social" (usually social sciences or the humanities) and another in "the technical" (usually engineering or the sciences and sometimes mathematics). This mechanism is widely practiced in experimental or ad hoc fashion across the institutions we reviewed, but is systematically deployed at Olin College. One of our interviewees described Olin's co-instructional model in great detail, focusing specifically on the extent to which multidisciplinary faculty come together not only for course delivery but also course design and student-team oversight (described as more like "coaching" than following a traditional instructor-student relationship). Olin is widely recognized for integrated education connecting

STEM expertise with a wide range of social and creative disciplinary perspectives, including history, anthropology, design, and the arts.

Another interviewee reflected on the need for diverse expertise to adequately represent "both" sides of the sociotechnical:

> The biggest practical aspect to it is that you have to have experts in both areas informing not only the curricular development, but then the teaching, the assessments…. It requires a team, sometimes of more than two people. For all of [our instructional interventions] we had two people that were developing them, but then we also would have to get input from even others besides us…. The pedagogy and delivery … would require additional support for evaluations or assessments or even putting together materials. We also lean heavily on a guest-expert approach for multiple reasons; … none of us holds all of the knowledge and expertise in any particular area…. It's important to sort of show that, "Yeah I'm your professor, but I don't know everything about engineering and art, so I'm going to have someone come in from the arts college that's just up the road to speak about that." So there's that as well.

The interviewee who above referenced the importance of more attention to convergence also alluded to co-instructional models as necessary for conveying the intricacies of this kind of work, differentiating it from mere application of engineering knowledge:

> Convergence requires a multidisciplinary perspective. [Convergence] problems are … complex. [They] require multiple disciplinary perspectives to come in and the ability to communicate among disciplines to share information, to partner with people that have expertise you don't around [problems] that are larger and more intractable. [This] differentiates convergence from your typical application.

In our assessment, co-instruction goes beyond assembling an array of disciplinary perspectives. It is impactful because of the interplay created between differently situated educators. Their give-and-take is itself part of the logic and the educational impact.

<u>Institutional Constraints: What limits our ability to achieve sociotechnical integration?</u>

In response to our questions about interviewees' specific activities for integration of content they might see as "social" and "technical", they repeatedly invoked the dynamic pressures institutions placed on reform efforts. In their experience, support from administrative leaders and institutions is crucial for determining the way integrative programs develop as well as for aligning with institutional priorities and philosophies. Student perspectives came up in several interviews, too. While for some, student demands on programs and institutions could motivate powerful reckoning with questions of justice and equity, there were limitations. One interviewee explained that following student demand and building "market-based" program offerings as "what our students want, [but] not what they need…. But how [would] they know [the difference]?" Similarly, other interviewees shared stories about students who were drawn to programs based on limited conceptions about what would serve them; they were clear that sociotechnical integration was not necessarily something that students could be expected to know about without significant educational scaffolding.

Next Steps in Sociotechnical Integration: Discussion

While we did not explicitly deploy the Smith et al. framework for sociotechnical integration (Figure 1) in our interviews, we can characterize these educational mechanisms using the framework. We believe that the layering of social and technical education typically aligns with Category 2: Mutual shaping. Our interviewees were explicit in identifying connections between social and technical dimensions of engineering, moving back and forth between the domains. Wholly humanities and social sciences coursework (H&SS) without explicit connections to engineering may fall into Category 1: Independence, whereas H&SS or similar coursework that systematically situates engineering or technology within various social contexts may approach Category 3: Pervasive social context.

Unfortunately, we did not collect detailed information about various co-teaching initiatives to assess where they might fall on the Smith et al. framework; however, we believe it is safe to assume that Category 1 can be eliminated given that the point of co-instruction is to put social and technical disciplinary perspectives into productive dialogue. We suspect Categories 2 and 3 are likely fair assignments of most co-teaching approaches, but that Category 4: Sociotechnical integration may describe occasional co-teaching environments, particularly those that persist over multiple iterations, where faculty are able to improve connections over time. This is a topic we must query further.

While the term “sociotechnical” is used across many engineering educational interventions, we were surprised to learn that it was not widely deployed as a core concept among our interviewees. In other words, a vision of engineering as sociotechnical practice rarely formed the conceptual foundation of educational interventions into engineering among our interviewees, at least not at the undergraduate level. While we collected compelling narratives of the different ways our interview participants were integrating “the social” with “the technical,” they rarely deployed “sociotechnical integration” terminology unprompted. When interviewing, we were often met with questions about what *we* meant by “sociotechnical integration.” While our interviewees would respond with their mechanisms and drivers for how they constructed the integration, they were not accustomed to describing it as such.

We speculate that either this concept is not foundational to our interviewees’ thinking, or that they do not connect with this phrasing in the same way that we do—perhaps they do not think it is accessible to or impactful for their students. It is perhaps ironic that we found this lack of organic engagement with the term “sociotechnical integration” among leaders in the field at this moment, when the term “sociotechnical” is so ascendent within engineering education reform scholarship. Nevertheless, all of our interviewees reflected thoughtfully on the role of sociotechnical approaches to engineering education once prompted. For example, one interviewee with a humanities background responded to our query by referencing her commitment to “holistic education” of engineers, going on to describe sociotechnical integration by refencing the mutual shaping among engineering, the social world, and the environment:

> Right, so thinking of how engineering is integrated … not only from the perspective of integrated engineering as an educational approach, but then also how engineering integrates into society, into culture, environments, human and nonhuman aspects of the built and natural environment. And

> thinking about not only how those things impact on engineering, but how engineering impacts upon those.

While our goal is to explore and refine educational programming in Category 4 of the Smith et al. framework, we must remind ourselves that the categorization scheme is not a hierarchy of conceptual superiority. All four of the categories are accurate in their own ways and useful for their own purposes, which is especially important to emphasize in engineering educational contexts. Deploying advanced social constructivist theory among engineering students who miss the point achieves none of our educational or pro-social engineering goals. The question is instead how to make each of the categories most impactful in helping to transform our educational outcomes and thereby helping our students to create greater social impact.

Next Steps in Sociotechnical Integration: A Proposal

After our research group finalized our interviewing, interview transcriptions, and light thematic coding, we scheduled a retreat to consolidate insights and propose a next-step in sociotechnical integration. Our goal was to advance our efforts in sociotechnical integration with a form of understanding and practice that best aligns with category 4 of the framework provided by Smith et al: with social and technical dimensions of a given phenomenon not only mutually shaped, but fully mutually constituted. What we came up with was a surprisingly discrete model of faculty professional development for our department, whose faculty identifies primarily as scholars in a) engineering and design education or b) the social sciences. This model extends from the team-teaching efforts described above but goes further to require instructional teams to define "integrated lessons" building upon each of their mutual disciplinary instructional traditions.

Our proposed instructional intervention is to focus on foundational engineering design "tools," defined broadly as sites for mutual understanding and collaboration. These "boundary objects" [22] can serve as an opportunity for learning by both STS- and engineering-trained educators with the goal of achieving robust sociotechnical integration. This integration is to be achieved via a sequence of three activities: First, an engineering-trained faculty member will demonstrate to our mixed faculty how they teach the tool to their students, including its conceptual foundations (if relevant), application, and possible limitations or constraints to application. Second, an STS-trained faculty member will demonstrate to the group how that same engineering design tool might be deconstructed and/or contextualized to highlight hidden assumptions or prescriptive orientations to problem solving that are integral to the tool. Third, both groups of faculty members will work together to explore strategies for bridging the prior two activities and creating new lessons at the intersection. This bridging activity will strive to create a common language to describe how the social and technical dimensions of the tool are, in fact, mutually constituted and then to devise educational activities that convey that mutual constitution of the social and technical dimensions of the tool; this will be taught in parallel with lessons on how to deploy the tool. We propose this full sequence of activities to be repeated for a variety of engineering design tools, refining both the shared language around and approach to teaching sociotechnical integration using design tools as the object lesson.

We have come to describe this collective effort as "learning the tool, contextualizing the tool, and teaching the tool as sociotechnical practice." This planned department-wide effort implements and theorizes sociotechnical integration from the ground up, via repeated modules addressing specific engineering design tools. Candidate tools include those our faculty are already responsible for teaching, such as SolidWorks CAD modeling and decision matrices, as well as those we aspire to extend coverage of, such as Arduino microcontrollers and 3-D printing. For each tool, our ultimate goal is to collectively co-construct innovative educational approaches for our students that move between learning how to effectively deploy the tool on its own terms and understanding those terms as both contingent and directional, not "neutral" in terms of their consequences or usage. In this way, we hope to move our entire department, faculty and students alike, progressively toward robust conceptualization of "sociotechnical" engineering practice.

This intervention leverages the multidisciplinary co-instructional model that was evident across our research into social content integration, but it does so in a way that engages co-instructors in a mutual-learning process—not just a common instructional activity characterized by turn-taking. This learning process exists at the intersection of technical engineering and educational STS logics. This approach draws on insights gleaned from our interviews but is notably enabled by the unique intellectual and disciplinary diversity of our department's faculty. While the core deliverables entail educational programming/activities, the process is flexible for both planned and opportunistic scholarly outputs, including seeing both the strengths and limitations of STS interventions in pedagogical spaces.

Conclusions: From Misalignments to Multiplicities

One interviewee identified an underlying challenge to deploying sociotechnical integration as a lever for educational transformation:

> You've got a lot of people who try things in their classes [who] don't have much support for larger curricular integration. There's not been a really strong attempt to develop a more coherent understanding and get partners…. And, lacking that, you have a bunch of faculty with a bunch of different opinions, who are going to be pulling in different directions.

We are sensitive to these divergences in educational reform initiatives, and we are hopeful that our proposed faculty development programming might help bridge those with "different opinions" to help them work better together. We recognize those differences are not restricted to distinctions between technical and social perspectives. By developing shared languages around and understandings of sociotechnical integration, we hope to craft educational interventions that converge to achieve greater instructional coherence to best support our engineering students.

The multiplicity of approaches to sociotechnical integration is both intellectually stimulating and presents a challenge for systematic consolidation of insights. Reform must respond effectively to narrow technical specialization and must be scalable beyond institutional configurations of expertise, curricular opportunity, and student interest. Through our insights and ongoing work, we hope to create engaging, relevant educational experiences for engineering students that builds upon content immediately legible as "engineering," while simultaneously and organically conveying the inherent "socialness" of that same content. We all strive to ensure our instructional activities are perceived by students as immediately relevant to their roles and identities *as engineers*, resulting in decisions based on functional outputs but also entailing interpretive flexibility and inherent contingency. We believe such approaches can produce educational interventions that capture advanced conceptualizations of sociotechnical integration, while still being accessible to engineering students and interested faculty alike.

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