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Engineering as Conflict: A Framing for Liberal Engineering Education

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Introduction

In this paper we use the framing of "engineering as conflict" to unpack tensions, historical context, and practice of a liberal engineering education. Engineers have long positioned themselves as "problem-solvers" uniquely situated to use technical knowledge to propose solutions to complex problems. Recent work has identified the need to better integrate nontechnical knowledge into engineering education as a way of reflecting the complex social and political landscapes that structure engineering practice (Reddy, Kleine, Parsons, & Nieusma 2023). Here we explore using a framework for "engineering as conflict" as a compelling practice of sociotechnical integration at the undergraduate level. Here, conflict refers to the practice or process of disagreement, difference of opinion, or tensions.

From the perspective of science and technology studies, conflict can be understood as central to understanding the consequences of engineering decision-making in society. Practically, conflict, in the form of "normal accidents" or instances of environmental injustice, provides occasions for record-keeping, for legal action, and for media attention (Perrow 1984). Historically, in the US context, conflict motivated and accelerated research and development in engineering (Lucena 2005). Analytically, conflict as a structure offers an opportunity to clarify differences in opinion and experience from the perspectives of engineers, political officials, corporate representatives, and community members.

From the perspective of engineering design, conflict offers an alternate space for reimagining engineering education as one informed by tensions (Cheville and Heywood, 2016) and inherent to the "wicked" or sociotechnical pursuit of engineering design (Coyne, 2005; Norman & Stapper, 2015).

We are writing from our positions as founding faculty members of an engineering department in a liberal arts institution coming from scholarly traditions in science and technology studies and engineering/engineering design education. In this paper, we hope to conceptualize "engineering as conflict" as an analytical framework for engineering liberal education and share examples from our curricular and program development work.

Context and positioning

Below we share our disciplinary backgrounds and current teaching contexts to help situate how we use the analytical category of *engineering as conflict* in courses we teach. Our backgrounds in different scholarly traditions inform the ways in which we approach engineering education, which we find are often in conflict, leading to a productive tension which we hope to unpack in this piece.

Jenna Tonn: I am a historian of science and technology and I co-designed and co-teach *Making the Modern World: Design, Ethics, and Engineering* (MMW) with an industrial systems engineer. MMW is a 6-credit course for first-year students that integrates the modern history of technology and engineering as it relates to equity and justice with an introduction to engineering fundamentals and engineering design. MMW fulfills a number of requirements for engineers and non-engineers. For all students, the course fulfills liberal arts Core Curriculum requirements in History II (Modern History), Natural Science, and Cultural Diversity. In addition, for students in the undergraduate human-centered engineering major, MMW also fulfills their first year "introduction to design" engineering requirement. This course includes weekly lectures, engineering design labs, and peer-led reflection sections.

Avneet Hira: I am an aerospace engineer trained in engineering education research and designed and have taught *Introduction to Human Centered Engineering* a 4-credit required course in the human-centered engineering major at our institution. The course is positioned to introduce students to commonly taught first year engineering concepts (Reid et al., 2018) including engineering drawing, CAD, descriptive statistics, physical prototyping and design research skills grounded in humanistic inquiry. For the 8-week design project in the course, students work with our project partners - a school that supports individuals with extensive support needs, to design assistive technologies. I also teach *Innovation through Design Thinking,* a first year course that fulfills students "introduction to design" engineering requirement and an open-ended project based engineering analysis lab for students in their second year.

Debates about sociotechnical integration in engineering education

One way in which we are conceptualizing *engineering as conflict* as a generative analytical category is to connect it to ongoing debates about the social versus the technical in engineering education. The dualism between the social and the technical in engineering (Cech, 2014) has impacted not just undergraduate engineering education but engineering practice, wherein a façade of objectivity attributed to the technical-only nature of engineering has affected both how engineers practice and are educated in engineering. In a qualitative analysis of practicing engineers' experiences, Jesiek et al. (2019) found how engineers often act as gatekeepers of sociotechnical values in engineering. Such practices have similarly been upheld in engineering pedagogy and culture by ascribing to an ideology of depoliticization where engineering is taught and modeled for undergraduate students in ways that insulate what is engineered, who is engineering, and how engineering is enacted from social and political considerations and context (Cech, & Sherick, 2015; Holly, Jr., 2021). Introducing students to engineering aligned with an ideology that decontextualizes and separates the social from the technical makes students conceptualize the social as an afterthought or, worse, unnecessary (Erickson et al., 2020).

Attempts at sociotechnical integration in engineering education are certainly not new. Neeley et al. (2019) used a text mining approach to chart the history of attempts at applying STS to engineering education, which often is enacted by adopting a sociotechnical approach to engineering education in the ASEE PEER repository. They found that while between 1996 - 1999, work in the repository was making a case for such an approach that integrated, the first half of the 2000s focused on communicating the importance of such an integration for individuals studying and not studying engineering, the second half focused on a more macro demonstration of "how science, technology, and society are interwoven," (p.1) and 2017 – 2018 moved to pedagogies focused on sociotechnical thinking and assessment techniques. A year after this study was presented, Erickson et al. (2020) made a case for sociotechnical thinking for not just courses that students are currently taking but the importance of the role of sociotechnical thinking to engage with problems later on in their careers. Indeed, the ability to 'get a job' is not the only and, as some would argue, a relatively narrow motivation for engineering liberal education (Nieusma, 2015).

Over the years, multiple approaches have been developed towards sociotechnical integration. These have included using real-world examples in engineering courses (Erickson et al., 2020), developing critical sociotechnical literacy through a place-based approach for learners to be able to engage with the impact of engineering and technology on their own communities and work towards a more just future (McGowan & Bell, 2020), and a dual-major strategy to ensure continuity and dynamism across programs (Nieusma, 2015). Martin et al. (2021) conducted a multi-level (individual, institutional, and policy) analysis that resulted in recommendations across levels for a reform in engineering ethics education that embraces the sociotechnical. Roberts & Lord (2020) also shared their experiences of a program-wide reform aimed at integrating the sociotechnical in engineering through faculty development, targeted cluster hiring, and dissemination of findings with other institutions. Chen et al. (2023) described how a focus on the “who” in engineering has supported sociotechnical integration, and based on data collected from students, such framing has supported the sociotechnical aspects being more memorable for students as compared to decontextualized technical elements.

In addition to sharing individual and institutional experiences of such integration, those mentioned above and other work have begun to unpack some of the intricacies of such implementation. This has included uncovering evidence for preference of some types of sociotechnical thinking among female-identifying students from data collected at the Colorado School of Mines and the University of Colorado Boulder (Swartz et al., 2019) and understanding the challenges for integration across different courses (Claussen et al., 2019). More recent work has focused on understanding how educators conceptualize and implement sociotechnical engagements, including interviews with select engineering educators to understand how individuals with different backgrounds and experiences integrate the social in their engineering teaching practices (Reddy et al., 2023) and similarities and differences between instructors' experiences with implementation of sociotechnical integrations (Blacklock et al., 2021).

In addressing sociotechnical integrations in engineering education, it is important to acknowledge how in unpacking the tension of conflict inherent to engineering education, faculty and students often put themselves at risk within institutions. Behind the facade of meritocracy, institutions prioritize certain values and behaviors (Bourdieu and Passerson, 1990). This can be understood through a lens of cultural production theory (Levinson, Foley, & Holland, 1996) that helps understand individual and collective agency in structural constraints, and Bowles, & Gintis' work (1976) where they characterize the primary role of education as one to reproduce labor i.e. workers for the workforce. Hence, when we attempt unpacking these tensions as individual faculty members, we go beyond managing our individual learning spaces. Further, engaging in scholarship and work that deviates from the hard coded "norms" in education may also make faculty and students who do such work to be considered less meritorious. Yet, as was pointed out in the thoughtful and constructive reviews of an earlier version of this paper, foregrounding conflict may help disrupt this cultural reproduction of values and behaviors.

Debates about sociotechnical integration through the use of history

A second way in which we are conceptualizing *engineering as conflict* as a generative analytical category is to connect it to the ways in which historians of science and technology and scholars of science and technology studies (STS) use historical methods to illuminate conflict, controversy, negotiations, and failure in engineering and technology. Engineering educators have documented many ways to integrate history of technology and science and technology studies into the engineering classroom. Reddy et al. (2023) recently found: "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 "the social" includes disciplines outside of history, curricular interventions based on the infusion of the historical past into new or established courses vary.

Kline (2001) has argued for the importance of integrating history and sociology of science and technology into the engineering classroom as a means of teaching engineering ethics. Wary of the lure of "disaster ethics," or an overemphasis on significant but rare engineering failures like Three-Mile Island or the Challenger accident which students might not relate to, Kline advocates balancing case studies with an analysis of "the everyday practice of engineering" that contributed to these failures (Kline 2001, p. 17-19). Beyond ethics, Vardalas and Geselowitz (2012) suggest that the history of technology can be used to support the ABET student outcome that focuses on understanding the "impact of engineering solutions in global, economic, environmental, and societal contexts." As they argue, "the historical approach would give the students the broadest view, and allow them to transcend the narrow perspective caused by focusing on the cultural milieu familiar to them." (Ibid, np.). One approach they suggest centers on developing modules anchored by "deep history," such as the evolution of ancient to premodern ship building technologies (Vardalas & Geselowitz). Another approach embeds history within a global history of engineering course as a way of advocating for "global competency" among engineering students (Downey et al., 2006, p.107). History in most of these endeavors ensures a ready form of contextualization of engineering (Kleine et al., 2023), which of course, also has its own ASEE-framed history (Neeley et al., 2019).

Engineering educators acknowledge how efforts to contextualize engineering using the past quickly come up against examples of tension and conflict within and without engineering. The topic itself invites a clear-eyed understanding of the contested role of the engineer (Layton 1986); the fraught historical gatekeeping of the engineering profession (Slaton 2010; Bix 2013); and the engineering professions' changing assessments of the impact of technology on society (Lucena 2005; Wisnioski 2012). Key to the historicization of engineering is looking to the past to illustrate concepts like technological determinism and sociotechnical systems, the latter which functions as STS-scholars' "unit analysis" (Johnson & Wetmore, 2007, p. 573). Conceptualizing the process of creating a sociotechnical system raises questions about responsibility for engineers in particular: "Building sociotechnical systems means building arrangements of people, what people do, and the way they interact with one another. Engineers contribute to building the quality and character of lives, the distribution of benefits and burdens, what people can and can't do, the risks of everyday life, and so on" (Johnson & Wetmore, 2007, p. 575). Historians of technology have pointed out that one cannot understand sociotechnical systems without attending to the breadth of sociotechnical complexity, including its users (Cowan 1983; Oudshoorn and Pinch, 2003); its environmental impact (Cronon 1992; LeCain 2009); its reshaping of conditions of labor (e.g. Chang 2019); and its transformative affective experiences (Schivelbusch 2014). Accessing the breadth of this complexity requires introducing students to ways in which engineering functions as a mode of conflict, negotiation, instability, and change.

Historical methods of identifying contestation, conflict, failure, and negotiation in technical fields have aided in dismantling narratives of linear progress in science and technology and to illuminate the complex ways in which technical endeavors intersect with societies. Classic examples in sociological studies of knowledge, such as Shapin and Schaffer's (1985) account of Hobbes' and Boyle's seventeenth-century debate about the air pump, illustrate how a "controversy studies" approach reveals how knowledge-making intersects with politics and claims about the social order (Jasanoff, 2019). In the history of technology, Pinch and Bijeker (1987) identified the importance of understanding conflicting uses, interpretations, and approaches to the emergence of technologies (in this case bicycles) before the stabilization of technical objects or systems. Similarly, Cowan (1985) identified how sifting through the graveyard of technical failures like the unsuccessful gas refrigerator is a vital strategy for reassessing the social, political, and economic factors that make or break commercial technologies. More recent historical work related to technology, disability, and design invites a reassessment of how the built world (Hendren, 2020) and its assumptions about the "normate body" (Hamraie, 2017) serve as a site of active contestation, conflict, failure, negotiation, and creativity for disabled users (Williamson, 2019). Similarly, ongoing scholarship related to decolonizing STS (Lyons et. al 2017) and decolonizing the history of science and technology (Anderson 2020) grapples with how notions of the social and technical as described from Euro-American perspectives carry with them histories of colonialism, imperialism, violence, and social and racial subjugation. Decolonizing scholars, in step with the turn toward global history, recover and center the knowledge-making of practitioners from a wide array of regions, geographies, and backgrounds (Soto Laveaga & Gómez 2018; Saraiva 2022) and seek to challenge and de-link these practices from Euro-American categories of knowledge (Gómez 2022; Mitra et. al 2023). Thus, there is a rich tradition of locating conflict as a central method of historical analysis in technical fields, a practice which we use in the liberal arts/engineering classroom and will elaborate on below.

Theoretical clarification

In the past, an ASEE panel has called upon engineering education to make space for conflict (Slaton et al., 2021). Engineering as conflict as an analytical category links together insights about engineering education and the practice of teaching engineering design and scholarly traditions from STS and the history of science and technology that have identified conflict and contestation as inherent to the process of technical knowledge-making. It offers a conceptual framework with which to hold together multiple perspectives, experiences, and knowledges about the practice and profession of engineering as well as the uneven impacts of sociotechnical systems. In what follows we offer examples of how we have approached engineering as conflict in two different classrooms, a first-year engineering design course for first-year engineers and a first-year interdisciplinary history and engineering studies course for all majors.

Histories of engineering as conflict: labor and productivity

In the summer of 2023, when I geared up to teach my fourth iteration of MMW questions of labor and technology were in the news with the strikes of the Writers Guild of America (WGA), the Screen Actors Guild-American Federation of Television and Radio Arts (SAG-AFTRA), and the United Auto Workers (UAW) (Brofenbrenner, 2023). The MMW syllabus has always included a module on work and power that centers on a historical analysis using primary and secondary sources of the emergence of large sociotechnical systems in the nineteenth-century from the differing perspectives of system builders and workers (Schmitt, 1930; Hughes, 2004). Given the ongoing labor actions in the news, I decided to both expand this module and highlight throughout the syllabus how the conflict over labor is a critical thru-line in the history of engineering and technology. Labor, in general, and Taylorism, in particular, is not a new site of discussion for engineering educators (Wisnioski, 2015, p. 249). But once I made this decision, I was surprised by how the analytical lens of engineering as conflict in relation to labor required me and the students to hold together both the incredible influence of engineers over time and the different ways in which technical solutions, embedded in complex sociotechnical systems, impact the experience of working in the modern world.

I will give two brief examples. First, each year, my colleague and I open our course with an interdisciplinary analysis of the Great Molasses Flood, a 1919 disaster that caused over two million gallons of molasses to flood Boston's North End killing twenty-one people and injuring over 150. While shoddy construction caused the tank failure, the fact that the tank was located in a dense Italian immigrant neighborhood with low citizenship rates and little political power meant that the company in charge, the Purity Distilling Company (a subsidiary of the United States Industrial Alcohol Company) could get away with little oversight. This event has an important labor backstory. Puerto Rico-born Isaac Gonzales, a non-union "general man" at Purity Distilling was hired in 1916 to help transfer molasses from incoming ships to the tank. Between 1916 and 1918, he witnessed the tank leaking molasses, saw workers painting the tank brown to cover the seepage, heard the tank groan with the addition of new shipments, and had nightmares about its failure. Although he repeatedly raised concerns to his supervisor and to the treasurer of the company, they dismissed them, leading Gonzales to quit out of fear of what would happen if the tank failed (Puleo, 2003). Reframing the Molasses Flood through Gonzales's perspective documents the lived experience of the fear of engineering failure, the lack of autonomy Gonzales had in his position, and the social vulnerability of a non-union laborer of color.

Second, several of the 2023 labor actions involved issues about the impact of emergent technologies on employment, from the WGA's and SAG-AFTRA's concerns about the use of generative AI to replace writers and actors (Scherer, 2024) to the UAW's concerns about how the auto industry's expected transition to electric vehicles has created a technological pretext for rolling back union protections (Ewing, 2023). In MMW, we discussed these current conflicts about worker rights, autonomy, and compensation within sociotechnical systems as having a long history linked to the social control of women and children in 19th century textile factories (Anonymous, 1841); efforts to manage Ford's deskilled, or unskilled, labor at his Highland Park automobile manufacturing plant (Meyer, 1981); the use of scheduling (Kantor, 2014) and productivity algorithms (Day, 2021) to control workers' roles and responsibilities; and realizations about the trauma experienced by social media content moderators (Chen, 2014; Newton, 2019). In each of these cases, compelling successes in engineering efficiency in terms of unimaginable output of textiles, cars, cups of coffee, consumer goods, and social media content occur in tension with workers' experiences of monotony, anxiety, and dehumanization.

Sitting in and acting from a place of conflict: design and being

In designing a course called Introduction to Human-Centered Engineering (as opposed to *Introduction to* or *First year* Engineering) I looked for ways to support students in developing a sense of being in addition to learning content in engineering liberal education. The metaphor of sitting in tension (Palmer, 1998) has always resonated with me when trying to make embodied sense of sociotechnical integrations. In the first few weeks of the semester I offer the students a framework of sitting in tension between creativity and criticality as engineers. I believe that creative production and problem solving is important to an engineering practice, but at the same time so is enacting criticality in what is created or sometimes making a decision to not create at all. I re-introduce this practice of sitting in tension with conflicting ideas when we work on physical prototyping labs and discuss what types of values engineering uphold and how they may create value and for whom (Friedman & Hendry, 2019).

A discussion we often have in both the design-based courses I teach is *whom* are we designing for or with? Desen Özkan and I (2021) developed a framework to introduce critical reflection in engineering design by creating prompts that ask the question "who/whom" at each step of the design for e.g. Whom is this design benefitting? Who is being counted in the data collection process? Whom is the design being attributed to? Whose problem is being solved? Through design milestones teams of students reflect on these questions within their teams which often results in dissonance and conflict e.g. students question their place in solving problems for others when it is improbable for them to have the same lived experiences as the communities they work with. They also often bring up the materials and supplies they "waste" in learning new prototyping methods e.g. wood, plastic and cloth. Such human-material conflict or conflict in understanding one's positionality is imperative in engineering work, and we discuss this in class through individual and group reflective dialog.

In the engineering analysis project-based class that I am teaching which was originally created by my colleague Jonathan Krones, we spend the first few weeks discussing project contexts for students to model and validate existing engineering analysis techniques. We try to structure the class such that teams of students can choose analysis problems in any context relevant to engineering and interesting to them. In discussing different contexts, some students brought up the conflict that Oppenheimer (likely prompted by the recent movie) found himself in as an engineer/scientist. Which led us down the path of discussing the role of an engineer in conflict and the conflict that engineers who work for the military or as military contractors might find themselves in balancing scientific curiosity, national security, and their own values. I found this to be an opportune time to bring back the tool of *tension* to help sit with and if needed act from as engineers. Conflict need not always be terminal in nature, it can be generative, it can make us engineer better.

Conclusion

Key to the analytical framework of engineering as conflict is a recognition of tension and uncertainty and an intention to develop a practice of identifying and holding this complexity in our work and in the classroom. At times both we and our students seek a resolution to the problems inherent in the work and history of engineering and engineering design. In reflecting on our experiences teaching from our own disciplinary expertise at the same institution and to many of the same undergraduate engineering students, one point that we have been thinking about is whether or not engineering as conflict has the promise of resolution. Will we strike the right balance between the technical and social in our programs of study? Will uncomfortable insights or self-truths lead to a better understanding of one's positionality or of the lived experience of users, especially those coming from very different lived experiences than our own? What is the right way to solve a problem if the problem itself is so complex and multifaceted? In the case of labor and productivity in the MMW classroom, we learn from history that while technologies have changed, there is an unsolved, underlying conflict between expectations of efficiency among system builders and experiences of satisfaction among workers. Thus, while we have made strides in the right direction to identify this conflict, as it were, we still have not resolved the systematic problems of asymmetries of power and labor inscribed into modern sociotechnical systems. In the engineering design classroom, we have identified that conflict is inherent to design and learned that the more we integrate the sociotechnical, the more students and practicing designers will find themselves in conflict and needing tools to act from or be able to refuse acting from conflict. Moving forward in our teaching, we seek to develop additional approaches related to reflecting on why the impulse to resolve conflict is so commonly shared.

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