Framing Learning Outcomes in Sociotechnical Engineering Design Education: The Role of Faculty Ontologies

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Introduction

In the past decade "sociotechnical literacies"—students' ability to understand the role of engineering work on people, communities, and societies as well as consider issues of implementation and acceptance of design solutions for those people, communities, and societies— became a core learning outcome of engineering education [1]. Now in engineering education, students are expected to integrate knowledge learned in the engineering sciences with design skillsets and processes to develop solutions to ill-structured engineering problems [2]. However, scholars are increasingly acknowledging that engineered solutions and the design process are situated in the social realities of the world, which means engineering both influences and is influenced by social considerations [3]. As a result, scholars frequently argue that it is necessary for engineering educators to develop and implement learning experiences that foster sociotechnical learning outcomes. Still, barriers to widespread adoption of sociotechnical design, such as concerns about student resistance, bans on teaching "divisive concepts," and (lack of) support for sociotechnical education, abound.

Scholars have conceptualized the factors shaping faculty pedagogical decision making at the individual (e.g., faculty's personal values, interests, motivations), structural (e.g., institutional support for pedagogical innovation), and societal levels (e.g., widespread sociopolitical influences on faculty pedagogical decisions) [4], [5]. The purpose of this research was to examine the factors shaping both whether faculty adopt sociotechnical learning activities in engineering design education, as well as how faculty deliver sociotechnical design education. Guided by the Academic Plan Model (APM) [5], we sought to understand how factors at various levels influence engineering faculty's pedagogical decisions and approaches to integrating sociotechnical concepts into their courses and projects.

Although existing research has described the sociopolitical influences on course decisions, less research visits the role of philosophical elements of faculty decision making, such as personal epistemologies or ontologies. Faculty's beliefs and perceptions about their academic field, the nature and purpose of education, and student behaviors are key contextual filters that influence course formation [5], [6]. Thus, in this particular research paper we present differing ontologies of education and engineering from faculty that teach sociotechnical engineering design in undergraduate courses. We map these ontologies onto particular teaching practices within the classrooms and onto desired engineering student learning outcomes of sociotechnical concepts. We sought to answer the following research questions:

1. How do contextual influences shape the pedagogical strategies engineering design faculty adopt in sociotechnical engineering design education?

Literature Review

Research on Faculty Pedagogical Decision Making

Recent research has sought to examine the factors that shape faculty pedagogical decision making. For example, Finelli and colleagues [7] examined factors that influence faculty adoption of effective teaching practices (e.g., active learning strategies) in engineering education, focusing particularly on the contextual features that inform faculty pedagogical decisions [7]. After a series of focus groups with engineering faculty, they pointed to individual factors, such as teaching self-efficacy and motivation, as well broader contextual factors such as institutional infrastructure or culture for pedagogical innovation, as key factors shaping faculty adoption of effective teaching strategies. Similarly, Carrero [4] used a comparative case study design to study the factors that influence faculty adoption of content related to diversity, equity, inclusion, and justice (DEIJ) in engineering education. Such a design allowed Carrero to example influences at various levels, including influences internal to the faculty member themselves (e.g., their personal values and dispositions), structural conditions (e.g., institutional missions and support for DEIJ, departmental support, academic autonomy), and broader sociopolitical conditions (e.g., current events, state and local policies, broader societal values). These studies consistently suggest that factors at differing levels of direct influence can impact faculty decision making in the classroom. In this research, we aim to add to this body of research to understand the external and internal influences on engineering faculty as they integrate sociotechnical engineering design concepts and skillsets in their classes.

Sociotechnical Design Education in Engineering: An Ongoing Debate

Debates about the role of "sociotechnical" education in engineering have only intensified over the past decade. Many engineering educators favor adopting sociotechnical pedagogies citing the role of engineering and emerging technology in mitigating or exacerbating inequalities for people, communities, and society [8]. Indeed, existing literature suggests exposing engineering students to activities that encourage sociotechnical thinking both supports students' engineering identities and broadens their engineering practices [9], [10], [11]. Still, debates about sociotechnical learning activities in engineering education persist. That is, beyond debates about whether sociotechnical pedagogies belong in engineering at all, scholars continue to debate what constitutes appropriate learning environments, teaching strategies, or learning outcomes. For example, particular learning goals for sociotechnical design education range from adjusting skills already taught in engineering design education, such as idea evaluation, to developing new orientations to engineering practice, like justice-oriented engineering. The disagreement, and resulting inconsistencies, among engineering educators as to the role of sociotechnical engineering within the curriculum compels engineering faculty to develop innovative pedagogies responsive to their own contextual circumstances.

Conceptual Framework

This research was guided, in part, by the Academic Plan Model (APM) articulated by Lattuca and Stark [5]. Broadly, the purpose of the APM is to "make explicit the many factors that influence the development of academic plans in colleges and universities" [5, p. 5]. To begin, Lattuca and Stark describe the curriculum in terms of an "academic plan" which entails the purposes, content, sequence, learners, instructional processes, instructional resources, and evaluation and adjustment strategies that shape students' experiences in college. They suggest that such a framing is applicable to the development, implementation, and analysis of curricular decisions at various levels—from a single learning activity within a course, to an entire course, program/major, or grouping of courses within a school, college, or broader university [5]. We frame sociotechnical engineering design education in terms of academic plans to position faculty to discuss how their courses are situated in their department's curriculum, as well as their course's relation to short-term institutional goals, broader institutional missions, and local and national policies.

We focus on various levels of internal and external contextual influences because the APM posits that influences at multiple levels can shape the development and implementation of academic plans. For example, the APM describes internal (i.e., to the institution, department) influences, such as an institution's mission, financial resources, student characteristics, and faculty governance structures, as important factors shaping academic plans. Two faculty members who share a commitment to social justice-oriented design education may be differently positioned to implement justice-oriented design education if, for example, institutional policies prohibit or undermine the inclusion of such concepts at one institution, while policies encourage and support teaching such concepts at another. Similarly, the APM points to external influences, such as accrediting agencies (e.g., ABET) and local, state, and national policies, as factors exerting influence on academic plans.

Importantly for this paper, within the APM, Lattuca and Stark [5] describe the contextual filters model of course planning, which articulates that both student and faculty, amongst other factors, influence course decisions (e.g., goals, content, sequence, and instruction). For example, the contextual filters model articulates faculty members' background and characteristics, their views about their academic fields, and their ideas about the purposes of education as elements of context that shape course decisions. Similarly, the contextual filters model describes student characteristics, program goals, and pragmatic factors such an institution and course sizes, as other factors shaping course decisions.

Methods

The data for this paper are from a series of semi-structured interviews conducted as a part of a larger mixed-methods research project. The study drew on a comparative case study (CCS) design that Carrero [4] argues is particularly appropriate for exploring, comparing, and contrasting how phenomena, such as faculty pedagogical decision making, unfolds across contexts and over time. We began by specifying five sociopolitical contexts and identifying institutions within those sociopolitical contexts that would serve as distinct cases.

Participants were recruited using a stratified purposive recruitment strategy [12]. A study team member first used publicly available faculty biographies on the institutional websites to identify potential participants that met the selection criteria. This list was then distributed to a faculty advisor at each university who acted as a liaison and reviewed the list of potential faculty participants to (a) verify that the faculty had, in fact, taught design courses and (b) suggest specific faculty who might offer insights germane to the research questions. We then sent emails to faculty containing recruitment surveys in batches based on departments consistent with the CCS design. We also stratified the recruitment process across multiple universities with different sociopolitical and institutional climates (e.g., in the state of Michigan vs. the state of Texas, private vs. land grant).

Currently, we have conducted 15 interviews with faculty from three different institutions. Demographic information including the faculty's primary department assignments are listed in Table 1. All 15 interviews were conducted by a single member of the study team who is trained in qualitative research methods and has experience with interviewing research participants. The interviews lasted approximately 60-90 minutes. Each interview was conducted remotely on Zoom with video and audio recording. The recordings were transcribed with a transcription software and then reviewed and cleaned for accuracy by another study team member.

The transcriptions from each of the interviews were analyzed by four researchers. The coding process followed an iterative, abductive process, which "starts with a set of theories and extends the, by looking for theoretical anomalous empirical cases" [13, p. 974]. During codebook development, the study team selected a subset of the interviews, which were coded by each of the researchers individually and then reconciled in a series of meetings. Consistent with abductive coding strategies [13], the APM provided a general theoretical basis for coding, which influenced the preliminary codes in the codebook. We added subsequent codes to the codebook collaboratively by reading and re-reading transcripts. The researchers then discussed the codes they identified and discussed their interpretations to clarify definitions of each code and add exemplary quotes.

Findings

In the following sections, we describe preliminary findings related to the ways that faculty describe the role of (a) the nature of technology, (b) the nature of engineering work, and (c) the nature and purpose of education, to their pedagogies. We argue that these views reflect personal ontologies and are informative for understanding why and how faculty implement sociotechnical engineering design pedagogies. Here, ontologies are defined both as the nature of reality (e.g., whether an entity exists), as well as the general features and relationships amongst components of some entity [14]. Guided by this definition, we argue faculty's personal ontologies about technology, engineering work, and engineering education, appear to frame whether and how faculty engage in sociotechnical pedagogies.

Ontologies about the Nature of Technology

To begin, faculty who self-reported that they implement sociotechnical design pedagogies regularly discussed the nature of technology, including the relationship between technology and people, communities, and society. For example, Malena (European American/White (non-Hispanic), Woman, Computer Science), described her approach to naming robots in her laboratory and class activities:

> *I have some opinions on robot gender and gendering robots, and like what that means. I try and have my robots be relatively gender neutral, somewhere in the non-binary, agender space, because if you think that gender is a thing that comes from within a person, and the robot does not have an interior life. The robot, sort of by definition, cannot have a gender, but we can certainly attribute gender to our robots… when you design a robot, making sure that your robot is not reinforcing inequities and injustices.*

Malena's comments highlighted her belief that technology can reinforce existing social hierarchies and inequities (i.e., a relationship between technology and the world). In drawing on this personal ontology, Malena made pedagogical choices around her language in the classroom to mitigate the potential for technology education to reinforce gendered social hierarchies. Karter similarly spoke to the ways that technology can reinforce racial exclusion, articulating his desire to prepare students to confront such exclusionary moments during the design process:

> *That when, I mean, I'd like them to go and when the boss says, there's an anecdote about the they're working on Siri voice recognition, and they're like, Oh, we got to design this to deal with accents and different sort of, like dialects and things. And somebody says, well, then we need to add, like, African American slang into this. And some manager says this is a premium product. We shouldn't waste our time with that. When the boss says that it's like this, is when you know it's time to fire the boss.*

These quotes speak to the ways that faculty's personal ontologies about the role of technology in systems of inequality shape their teaching broadly, and their motivations for integrating sociotechnical learning experiences specifically.

Ontologies about the Nature of Engineering Work

Just as faculty discussed the nature of technology as a motivation for engaging in sociotechnical pedagogies, faculty also spoke more broadly about what it means to be an engineer and the nature of engineering work. For example, Cruz (European American/White (non-Hispanic), Man, Aerospace Engineering) spoke about his personal ontology about the nature of engineering work, and rejected the view that mathematics and science knowledge are solely the basis of engineering:

> *I mean, there's nothing wrong with that [learning decontextualized knowledge or skills]. I mean, I think all of those things are like good things to learn and good things to practice, but it's a very narrow… it's like engineering from the viewpoint of a mathematician or a scientist, and that stuff is good, but it's not what engineering really is.*

Cruz later laid his perspective bare, connecting these beliefs to his sociotechnical pedagogies:

> *So like, I think in aerospace engineering we can be, I mean, in all of engineering, we can be a bit like, technology focused. And there's a line from Jurassic Park that I like a lot where they say your scientists were too preoccupied with whether they could, they didn't stop to think if they should. And like I think that is very true, and it's and I think in space flight, we can do a lot without stopping to think if we should do a lot. And so, like, I'm trying to get students to think about that, and I really like to bring forward perspectives that they probably haven't heard…I think ignoring the sociotechnical and ethical, sort of societal, ethical aspects of your job, is the most immoral, unethical position.*

Others spoke about the nature of engineering work as it is situated in a broader sociopolitical context. For example, Lake (European American/White (non-Hispanic), genderqueer, Other Sub-Disciplines) noted that engineering has historically been defined by its relation to the defense industry, which framed her thoughts about how educational activities can make students aware of that broader context.

> *And then there's another example about how more generally, like the relationship between engineering and the defense industry and war and stuff like that. So, it kind of just gets them [the engineering students] thinking about, okay, how is the work I'm doing related to all of these other kind of like complex things, and what kind of assumptions are we working with when we're doing engineering work?*

These beliefs, values, and assumptions about the nature of engineering work informed faculty pedagogical decisions both in that faculty appeared to (a) want to address dominant ontologies in the discipline (e.g., the assumption about the inextricable relationship between engineering and the defense industry) and (b) prepare students for the reality of the discipline they were studying to join.

Ontologies about the Nature of Engineering Education

Finally, faculty discussed personal ontologies about the nature of engineering education as an important motivation for their decisions to implement sociotechnical pedagogies. Participants' personal ontologies about the nature of engineering education included their beliefs about the purpose of education, their assumptions about students (e.g., student goals, values, learning needs), and their role as educators. For example, Malena shared that her assumption about her relation to students, and the belief that some students must be exposed to sociotechnical concepts that they may not otherwise have been exposed to, guided her thoughts about her roles and responsibilities as an engineering educator:

> *…that I need to, let's say, bring along people who've never thought about this before in their lives, and I have a responsibility as an educator to gently help them along their journey of understanding, to introduce the ideas understand, if they're not always getting it, quote, unquote, right*

These comments were related to faculty ontologies about the nature of engineering education, including her assumptions about student prior knowledge and the efficacy of existing learning opportunities in engineering education for fostering students' sociotechnical repertoires. Other faculty spoke about the role of engineering in our broader society, and how engineering education can be used as a tool to foster students' awareness of their responsibility as an engineer. For example, Lake highlights how their beliefs about the relationship between engineering and the defense industry are intertwined with her role as an educator to present resources to students to critically consider the responsibility of engineers to people and communities:

> *And so in incorporating those readings [on social justice], I'm trying to get students to think more about, you know, not just being a good engineer, as in, like meeting the needs of the people who are paying you, but also thinking about what impact you want to have on the world and what responsibility you have to other groups of people. In some of my other courses, like robotics, the second year [Course Name] I teach…and that one is much more kind of like, explicitly about meeting the needs of like, real people.*

These comments suggest that engineering education is not just professional preparation for nameless, unknown roles, instead engineering professors consider education as a space to translate their personal ontologies about the nature of engineering work and engineering education into pedagogical practices. Faculty also consider the role of the discipline more broadly, its position in broader sociopolitical structures, as well as their position with relation to students, when choosing to implement sociotechnical design pedagogies.

Conclusions

Future Directions: Implications for Teaching and Learning

Our future work will continue to examine faculty adoption of sociotechnical design pedagogies across sociopolitical contexts. To date, we have collected interview data across Massachusetts, Michigan, and California, though we expect to continue data collection in other sociopolitical contexts (e.g., Florida, Texas). We presuppose that that data collection across these contexts will allow for conclusions about the ways that different contextual factors shape faculty pedagogical decision making, with implications for the learning experiences engineering students encounter and, by extension, students' realized learning outcomes. The debates and differing beliefs surrounding sociotechnical engineering design in engineering education make it necessary to understand the contextual factors on faculty's pedagogical decisions before offering unhelpful support to faculty.

Additionally, several scholars have used lessons learned from research on faculty pedagogical decision making to develop faculty learning opportunities that support pedagogical innovation. For example, Finelli and colleagues' [7] work examining factors that inhibit faculty adoption of effective teaching practices later resulted in the development of faculty workshops for supporting faculty adoption of active learning pedagogies [15]. Their work offers support for the idea that focused workshops centered on pedagogical change and innovation can have material impacts on teaching practices in the classroom. Our next phase in this work will entail examining the ways faculty implement sociotechnical learning experiences in the classroom, with the goal of developing workshops to support faculty pedagogical development.

Acknowledgements

This study was supported by the National Science Foundation under Grant NSF Award Number 2340238. The opinions expressed here do not reflect the opinions of NSF, and no official endorsement should be inferred.

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Appendix A: Participant Sociodemographic Characteristics

Table 1
Participant Characteristics

Gender		
	Woman	7
	Man	7
	Genderqueer	1
Race/Ethnicity		
	European American/White (non-Hispanic)	12
	African American/Black (non-Hispanic)	2
	Middle Eastern/Arab	1
	Asian American	1
Discipline		
	Aerospace Engineering	1
	Biomedical Engineering	1
	Chemical Engineering	1
	Civil Engineering	1
	Computer Science	2
	Engineering Education	1
	Human Factors Engineering	1
	Industrial and Operation Engineering	2
	Mechanical Engineering	2
	Space Science and Engineering	1
	Other	2

Note: Demographic information has been truncated to preserve confidentiality