Tensions in Applying a Design Thinking Approach to Address Barriers to Increasing Diversity and Inclusion in a Large, Legacy Engineering Program

Introduction

We are focusing on three interconnected issues that negatively impact engineering disciplinary cultures: (1) diversity and inclusion issues that continue to plague engineering programs; (2) lack of adequate preparation for professional practices; (3) and exclusionary engineering disciplinary cultures that privilege technical knowledge over other forms of knowledge [1]. Although much effort has been devoted to these issues, traditional strategic and problem-solving orientations have not resulted in deep cultural transformations in many engineering programs. We posit that these three issues that are wicked problems. Wicked problems are ambiguous, interrelated and require complex problem-scoping and solutions that are not amenable with traditional and linear strategic planning and problem-solving orientations [2].

As design thinking provides an approach to solve complex problems that occur in organizational cultures [3], we argue that these wicked problems of engineering education cultures might be best understood and resolved through design thinking. As Elsbach and Stigliani contend, "the effective use of design thinking tools in organizations had a profound effect on organizational culture" [3, p. 2279].

However, not all organizational cultures support design thinking approaches well. Despite increasing calls to teach design as a central part of professional formation (e.g., ABET, National Academy of Engineers, etc.), many engineering programs, especially larger, legacy programs have not embraced fundamental design thinking [4-5] strategies or values [6-7]. According to Godfrey and Parker, many engineering cultures are characterized by linear epistemologies, "black and white" approaches to problem solving, and strategic "top down" ways of designing [8]. In contrast, design thinking approaches are characterized by ways of thinking and designing that prioritize prototyping, multiple stakeholder perspectives, and iterative problem-solving to address complex problems.

In this paper, we examine the effectiveness of design thinking as a tool to address wicked problems in engineering education cultures, and the role of engineering culture itself in shaping the application and effectiveness of design thinking. More specially, we evaluate the role of design thinking in seeking cultural transformation at a School of Electrical and Computer Engineering (ECE) at Purdue University. We analyze interviews of members of the School after they participated in six design thinking sessions. Our previous research explored the effect of design thinking sessions on participant understanding of diversity and inclusion in biomedical engineering [9]. Herein, we explore participant experiences of design thinking sessions toward cultural change efforts regarding diversity and inclusion (D&I) within professional formation in ECE. We identified three tensions (push/pull dynamics of contradictions) that emerged from the participants' experiences in the design sessions [10]. We conclude by discussing our emerging insights into the effectiveness of design thinking toward cultural change efforts in engineering.

Background

The Evolution of Engineering Cultures

To enact organizational culture change, an understanding of the organization's cultural values and norms is critical. Particularly within engineering contexts, Godfrey and Parker cautioned that "if the espoused values inherent in any proposed change did not reflect enacted values at an "operational level," change would be difficult to sustain" [8, p. 19]. That is, any change that occurs must consider the organizational values, norms, and ideals that are both spoken and unspoken or taken for granted. Culture has been defined in a variety of ways, but we borrow from Schein, who characterized culture as:

> …a pattern of shared basic assumptions that the group learned as it solved its problems of external adaptation and internal integration, that has worked well enough to be considered value, and therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems [11, p. 12].

Building from Schein, engineering cultures are often constituted around historical events, which aid in creating and establishing norms of the field. For example, Villanueva and Nadelson conducted a survey to assess engineering students' understanding of their professional identity based on historical references toward engineering identities (e.g., Mediator, Designer/Tinkerer, and 21st Century) [12]. They found students' perceptions of their professional identities were not aligned with current, 21st Century socio-technical engineering practice that seeks to address real-world problems; rather, the students were more aligned with historical references that viewed engineers as problem-solvers and tinkerers in society. Villanueva and Nadelson's study provides insight into why and how engineering cultures are resistant to change and, by extension, affect the professional formation of engineers.

Resistance to change has been showcased in electrical and computer engineering (ECE) contexts. Considering this paper's focus on ECE, Jesiek and Jamieson traced the history of ECE through a series of historical moments that coincided with many of the social, cultural, and technological evolutions since the late 1800s [13]. Citing the recurring fragmentation trend within ECE (e.g., as technology evolved in society, electrical and computer engineers' expertise became increasingly specialized into siloed sub-fields with little overlap), Jesiek and Jamieson shed light on recurring issues pertaining to both (1) professional formation and (2) diversity and inclusion in ECE. That is, as a field, ECE promotes "negative stereotypes and masculine cultural dynamics in…both school and workplace settings" [13, p. 4570]. These cultural elements continue to create exclusionary practices and are a product of what Godfrey called "traditional" forms of engineering cultures [14].

Since the late 1990s, there have been gradual shifts in curricula that have attempted to disrupt these traditional cultural dynamics, with one possibility for change being the integration of design. Dym called upon engineering programs to make design "the *backbone* of engineering curricula" [2, p. 146]. Since then, some engineering programs across the country have made attempts to embed design into *all* aspects of the engineering curriculum and educational cultures. Aspects of the design process (e.g., the encouragement of creativity, innovation, and convergent-divergent thinking) are central to addressing modern engineering problems [15] and are helpful

in the cultivation of informed and expert designers [16]. When embedded and central to engineering cultures and pedagogy, scholars have argued that design provides students the possibilities to gain a greater tolerance for ambiguity, adopt multiperspectival approaches to problem-framing, and, ultimately, become informed designers [17]. Crismond and Adams developed the Informed Design Learning and Teaching Matrix that presented strategies and practices aimed at helping students move from novice to informed designers [16]. The Informed Design Learning and Teaching Matrix helps "by directing teachers' attention to common design misconceptions and habits of mind of beginning designers, suggesting performances that students might achieve as informed designers" [16, p. 775]. Through use of this matrix and associated design activities, novice engineers can grapple with increasingly ill-formed or non-routine problems thus preparing them for real world engineering tasks and for the grand challenges that often are described as wicked problems.

Wicked Design Problems: Engineering's Diversity and Inclusion Issues

Wicked problems are present in a variety of organizations and organizational cultures. Design thinking utilizes understanding and observations of human needs to address abstract and complex issues like wicked problems [18]. We consider diversity (e.g., representation) and inclusion (e.g., belonging) (D&I) issues within engineering to be wicked problems. There have been efforts to increase minority representation in both engineering programs and workforce; however, the representation and inclusion of difference continue to be lacking with profound consequences for membership, innovation, and engineering occupations [19].

For example, gender issues within engineering are well-documented [20]. Women earn close to 60% of all bachelor's degrees in the United States, yet less than 20% of those are from engineering fields [21]. These numbers are not surprising considering the wealth of evidence on the impact of retention because of "chilly climates" wherein cultures are not supportive and "cold" or unhospitable to outsiders [22, 23]. For instance, Tonso showcased the explicit ways that women are often subordinated in engineering cultures as "women were hypervisible on campus but were in time made invisible as members" of the engineering programs [24, p. 292]. Other studies have examined minority students experiences in engineering program and cultures, which have been useful in illuminating the racialized and gendered prototypes of the "ideal engineering student" to be White and male in engineering institutions [25]. Despite a wealth of scholarly evidence and approaches to address these persistent issues, the underlying cultural dynamics that promote D&I issues in engineering continue.

Thus, engineering cultures (e.g., engineering programs) may be an ideal site to explore the effectiveness of design thinking practices and processes [3]. Not only is design thinking suited to addressing wicked and ill-formed problems like cultural change and integration of D&I into a traditional masculine culture, but many engineering programs recognize design as a critical way of thinking, doing, and valuing engineering. Thus, the solution is consistent with cultural practices and language. It would be logical for engineering to embed design thinking and design skills into processes of professional formation and into engineering curricula; however, given the seeming inflexible nature of some engineering programs and cultures, the effectiveness of these types of change efforts is less studied.

As such, we explore participants' experiences regarding D&I change efforts within the School of ECE at Purdue University. By examining these participants' experiences and belief in their capacity and agency to change an engineering culture, our study sheds light on (1) the potential effectiveness of design thinking tools and paradigms toward cultural change, and (2) illuminating potential tensions that persist within organizational culture that can stymy progress and change efforts. As such, we are guided by the following research question:

RQ1: How effective is a design thinking approach for addressing D&I issues in ECE?

Methods

Study Context

The research reported in this paper is part of a larger project funded by the National Science Foundation. That project uses the three phases of design thinking (Inspiration, Ideation, and Implementation) to understand and to attempt to transform educational cultures of engineering around diversity and inclusion (D&I) [1]. The research project is a comparative study focused on undergraduate education of two engineering programs: Electrical and Computer Engineering (ECE) and Biomedical Engineering at Purdue University.

Design Sessions & Interview Participants

The design sessions refer to a series of six sessions over the course of one academic semester in 2018. The sessions were designed and facilitated by expert members of the research team who have a combined 25 years of experience in teaching and leading design efforts in both academe and industry. The curriculum was created using a variety of materials and tools from sources including from Stanford's d.school [26] and from consultations with an alumna of the ECE program who has 30+ years of experience working with design thinking at a large, automotive company. The 21 participants in the ECE design sessions included ECE faculty, staff, undergraduate and graduate students, and an administrator from the intercultural learning center at the university. The sessions occurred every other week and lasted for 90 minutes. Table 1 briefly describes the content of each session giving attention to goals and key activities.

TABLE 1
DESIGN SESSION DESCRIPTIONS

DESIGN SESSION	TOPIC/GOAL	KEY ACTIVITIES
Design Session 1	Understanding One's Professional Journey	Mapping individuals' professional journey
Design Session 2	Understanding Diversity and Inclusion Issues in ECE	Reflecting on professional journey maps, creating prototypical journey maps based on identity groups (e.g., women, men, international, etc.)
Design Session 3	Understanding Diversity and Inclusion Issues in the ECE context	Discussing research team's interview study from the prior year
Design Session 4	Creating Design Challenges Based on Problem Scoping/Framing from Design Sessions 1-3	Brainstorming potential components of solutions that could address the D&I issues in ECE
Design Session 5	Developing Design Challenges	Consolidating components of the design challenges into an implementable solution.
Design Session 6	Presenting Prototype Solutions that Address D&I Issues in ECE	Developing an implementation plan for the solution, presenting to the Design Session participants

The series of design sessions culminated in development of several potential prototypes (e.g., a graduate teaching assistant training, a junior-level professional development seminar, and a vertical integrated design program) that could be implemented to address the interrelated issues regarding D&I, preparation for practice, and integrated socio-technical understanding of engineering within ECE.

Following the conclusion of the design sessions, requests for a follow-up interview regarding their participation in the design sessions were sent to the 21 participants. Of the 21, seven individuals voluntarily participated in the interviews by the first author. Table 2 provides a description of each participant, their pseudonym, and role in ECE.

TABLE 2
INFORMATION ABOUT PARTICIPANTS

PARTICIPANT PSEUDONYM	ROLE WITHIN ECE	GENDER
Christina	Alumna, Electrical Engineering	Female
Christy	Graduate student, Computer Engineering	Female
Claudia	Junior, Electrical Engineering	Female
Cordelia	Senior, Electrical Engineering	Female
Esme	Staff member, ECE	Female
Eula	Staff member, University Intercultural Learning Center	Female
Ethan	Faculty, ECE	Male

Data Collection

This study utilized semi-structured, in-depth interviews aimed at understanding participants' perceptions of their experiences in the design sessions. Participants were asked about their overall perception of the design sessions ("Describe your experience in the ECE Design Sessions?"), their connection to D&I issues in ECE ("Before the Design Sessions, what did you

think about diversity and inclusion in ECE? After the Design Sessions, how did your thinking change?"). Participants were also asked about how they might change the design sessions to be more effective, their own self learning ("What did you learn about yourself as you worked in this group? What does that reveal about how engineers should be?"), and potential "ripple effects" that they saw occurring in ECE because of the Design Sessions.

Interviews lasted from 27 minutes to 54 minutes, with an average interview lasting 38 minutes. The interview files were then recorded by a third-party transcription service, which generated 95 pages of interview (an average of 13.5 pages per interview). The interviews were de-identified to protect participant confidentiality; participants were given pseudonyms. Our analysis also includes the first-author's notes from the both the interviews and the design sessions. The first-author facilitated and observed every ECE Design Session. Both additional points of data helped to contextualize the interview participants' descriptions of events and moments in the Design Sessions. All data collection materials were approved by IRB.

Analysis

Our data analysis was informed by the constant comparative method for thematic analysis of Corbin and Strauss [27]. Using NVivo, the first author read through all the transcripts and notes, line by line, to compile a list of open codes. During the second round of coding, the first author began grouping the open codes into higher-level categories. For example, codes like "design sessions were productive," "design sessions inspiring micro-level actions," and "design sessions as generative" were grouped into larger family categories like "Design sessions as starting point for change."

With the research question in mind, the first author gave attention to issues, moments, and descriptions where the effectiveness of design thinking was referenced. Several tensions emerged in the final round of coding. As Putnam, Fairhurst, and Banghart (2016) argued, tensions "are feeling states, ones that often result from frustration, blockage, uncertainty, and even paralysis that individuals face in dealing with contradictions and paradoxes" (p. 68). Tensions develop as individuals experience them in and throughout organizational cultures. Such experiences were often described throughout the interviews. Throughout the analysis process, the first author took notes to brainstorm and identify larger thematic tensions that appeared through the participants' descriptions of their experiences.

Finally, the results from the preliminary analysis were presented to the research team and design session participants for refinement and feedback. Members of the research team have worked in electrical and computer engineering, engineering education, and biomedical engineering.

Findings

Despite an intentionally structured and facilitated design curriculum, several tensions related to participants' experiences and perceptions of the effectiveness of the design sessions were identified from the follow-up interviews. That is, they found the design process both confusing and helpful. Second, they described internal tensions of what could and could not be discussed

during the process. Third, they had an uncertainty and lack of clarity on who had responsibility for enacting organizational and cultural change in the program.

Tension #1: The design process was both confusing and helpful.

Tension #1 shed light on participants' overall impression of the design process. Participants described their impressions in contradictory ways. On one hand, participants described the design process as confusing. Specifically, they referenced the open-ended nature of design, their uncertainty on the progress of the process, and repetitive aspects of design as sources of confusion. On the other hand, participants noted that the design process was helpful. That is, participants referred to design as useful for encouraging participant buy-in, which helped to deepen participants' understanding systemic D&I issues within ECE, which can be challenging to identify and discuss.

Participants expressed that the process was confusing. That is, participants felt uncomfortable and uncertain with the open-ended approach of the design process; the process appears to many to lack clarity, definition, and purpose, which may have stymied the opportunities for depth of understanding and creation of solutions toward D&I issues within ECE. For instance, Claudia, a junior in electrical engineering, described the confusion in the following way:

> Sometimes there was a lack of clarity of the goal of the discussion that we were going towards…I mean there were sometimes where we'd just project what we'd be talking about, but sometimes I think a bit more organization on that would be helpful. I mean, you don't want to restrict the conversation, but making sure people kind of know what the angle of what they're talking about is.

To Claudia and others, the vagueness of the design process prompted the participants to reflect, "Where is this going?" Another participant, Ethan, an assistant professor in ECE, drew upon his own research and professional background in design to illustrate the conceptual murkiness of the design sessions. Drawing from his own professional expertise in design, Ethan continually asked the interviewers about whether the design sessions were using design thinking or co-design during the interview as he noted that he often had these questions during the design sessions. Both design approaches are similar perspectives and processes; however, the result of the processes can be different [28]. To Ethan, this definitional uncertainty added to his impression regarding the larger confusion surrounding the design process.

Other times, the design process seemed to be repetitive. Cordelia, a senior in electrical engineering, recalled, "A lot of times that we would just beat around the bush and talk about the same idea multiple times and spread it out to three different things, but it could be incorporated into one major topic." In sum, the confusion regarding the process, the definition, and the goals of the sessions may have affected participants' contributions and the prototypes generated. Despite these descriptions of the design sessions, most of the interview participants characterized the design sessions as effective in addressing ECE issues.

Whereas some described the process adopted for the design sessions as confusing, others were comfortable with its iterative converging-diverging nature. The ambiguous nature of the design process was seen positively when Esme, a staff member in ECE, shared,

> It rarely felt like okay they [the research team] have this overarching structure and they're really going to make us go in this direction. We're being funneled. It didn't usually feel like that. And I think, again starting at the beginning, helped everybody feel invested in it. And sort of letting it get messy for a while, I think was useful, and I think you guys did a good job of explaining that at the beginning that this is going to look messy and like we're not making progress for a little bit. But then you're going to see this converge.

The ambiguity of the design structure was a helpful tool for encouraging both buy-in and engagement throughout the six sessions.

Additionally, participants explained that specific activities built into the design sessions encouraged deeper conversations regarding underlying D&I issues in ECE. Using two different metaphors, Christina, a recent alumna of the ECE program, described the sessions as "like putting a flashlight on" and ripping "off the Band-Aid™." These metaphors provided a possible insight into how specific design activities unearthed topics and problems within ECE. More specifically, almost all participants described activities like small group discussion as particularly useful in understanding D&I issues in ECE. For example, Eula, a staff member from the university's intercultural learning center, argued, "The small groups were really great for generating ideas." Others like Ethan shared that the small groups prompted "really constructive discussions that came out of it […and] saw people finding common ground in unexpected ways." As an example of Ethan's claim, the students interviewed frequently expressed surprise that the faculty members involved in the design session also cared about D&I issues. Some, like Christy, a graduate student in computer engineering, leveraged participation in the design sessions to build stronger relationships with other faculty members that participated in the design sessions. Building upon both Eula and Ethan's assertions, Esme noted the small group discussions were effective at creating a space that fostered different perspectives on issues in ECE, and useful in creating diverse solutions. She proffered:

> Even within a group of like four or five in that room, you were going to have a lot of different perspectives. And sometimes the, I think if we had just a big group discussion, a lot of those perspectives would have been lost. But because we had these smaller group discussions we were able to sort of assimilate all of them into these coherent thoughts and then report out…Especially the beginning brainstorming, what these problems are, and then seeing how we could group them. And maybe find solutions that addressed more than one at a time.

To Esme and others, the inclusion of activities like small group discussions in the design sessions were examples of how the design session structure facilitated the prototyping process. Sentiments like Eula's and Esme's were shared throughout the interviews and relate to the second tension that emerged in the interviews.

Key Takeaway from Tension #1. Tension #1 shed light on two key areas of the ECE culture. First, this tension showcased the lack of cultural relevance design has within ECE. This was evident in participants' lack of understanding of design, design processes, and design thinking (e.g., the process was confusing, repetitive, and ambiguous). Second, despite this challenge, the design thinking approach was helpful for developing a more thorough and nuanced understanding of D&I perspectives and issues in ECE.

Tension #2: The design process included interpersonal dynamics that both encouraged sharing and restraint in what participants could express.

As previously mentioned, at the heart of the research project is an examination of how design thinking (and tools) may be utilized and leveraged to address D&I issues within engineering cultures. The interview participants described the design sessions as useful in illuminating systemic issues and barriers in ECE through the creation of a space that centered empathy and vulnerability for participants' experiences. Given the design sessions focus on illuminating D&I issues in ECE, one of the most powerful recurring elements of the sessions were moments where participants shared their personal stories. Participants' personal stories helped to frame and provide context to institutional issues in ECE surrounding class, race, and gender.

For participants like Christina, a recent alumna of the electrical engineering program, the design sessions offered an opportunity to view others' perspectives:

> Hearing people's stories as a way to say, "This is the best way that we should address this." For example, I know that there was at one point where we were talking about how being from a different country or being raised in the US has given you different points of view. At that point, people were starting to share personal stories. I think that was very powerful. It was powerful not only because it was an example of a question that was being posed, also showed a point of view. I think that sharing those stories with people you don't know can very much put you into a vulnerable spot. People could take it wrong or people can't. I think that for all of the students and the faculty as well to be able to share these stories or be open to say, "Yeah. Well, people are going to now, either critique me for it or they are going to accept this and try to help me sort this out."

One story shared was referenced in several interviews. Claudia recalled the following experience as a moment wherein personal stories encouraged different perspectives:

> I remember [Credence], talking about the financial burden of college and how he wasn't as financially secure. And I think that's something. Because I'm financially secure going into college, and so I just didn't really think about that being something that would ... and I can definitely see how that would impact your ECE experience, just the stress of that. And so that gave me like, "Oh, this can be another part of diversity." So that was an instance.

Credence's willingness to talk openly about the financial burden of attending college recurred throughout several of the interviews, and spurred participants to consider different issues that exist within ECE. Referring to Credence, Eula shared,

> I mean we were looking a little bit more at cultural and I think the socioeconomic, some of the students were like no, this is a real struggle for a lot of students and I think gets overlooked. And so, I think, again, these sessions were designed really well so that people felt comfortable saying I'm not sure we've considered this group.

Put simply, the design sessions' structure and activities encouraged openness and willingness to listen to others' perspectives and experiences.

For most, the design sessions cultivated an atmosphere of respect and empathy that supported individuals to share; however, two participants recounted experiences that ran counter to this idea.

Two participants perceived an obliviousness of power dynamics (e.g., gender and position at the university), which stymied individuals' willingness to share. Christy revealed a moment that occurred in the small groups that was particularly challenging and disappointing to her:

> What happened was the one guy student was talking about how great he thought office hours were and professors were so approachable and that was really great, and he didn't know that, and he should have known that sooner. And then the professor was like, "Yeah, yeah that's true." And then I said my experience was like I was never welcomed to office hours, and I was always chastised almost for being there and they were like, "We don't like free loaders, that's why." That was like, are you...That's what happened and after that happened I looked back and that's probably why I really don't go to office hours anymore…Looking back, probably my first few semesters I tried to go to office hours or TA's and I would not find them helpful at all, so I stopped going and that's probably something I tried to forget about or overlook for a few years. I just used other resources, I used my friends and internet. That's something...I tried to gloss over that stuff.

To Christy, this instance triggered several negative moments that she had in ECE and was a sad reminder of the lack of support she felt during her undergraduate experiences. This moment continued to unfold throughout Christy's interview, and, each time it was mentioned, Christy's described a gendered bias from her male counterparts—particularly from this professor.

Related to Christy's experience, another barrier to open sharing of ideas, experiences, and opinion was the unacknowledged positional/hierarchical differences of faculty and staff members. Ethan described moments of being hyper-aware of the differences in positional power in what and how he shared his opinions, noting that "there are people in this group who are quite influential in my ultimate employment." Ethan's concerns about sharing were related to questioning and critiquing institutional practices. To him, there were both personal and institutional concerns about liability, confidentiality. He recommended that future design sessions "provide even more specific ground rules with respect to confidentiality and potential legal issues for the institution upfront so that people understand the expectation and the level of safety that can be expected." Ethan did adopt a workaround for discerning what was and was not appropriate to share in the design sessions, noting, "I resolved it by just whispering it to somebody and saying, 'hey is it okay to talk about this.' I know it's a little tough."

Key Takeaway from Tension #2. There was a difficulty in managing both openness and restraint in what could and not be shared. Often, this tension emerged through the presence of power dynamics in ECE (e.g., status at the university, seeming invisible barriers to success, and gender dynamic). The power dynamics in ECE culture often ignored invisible forms of D&I (e.g., socioeconomic issues) that impact students, and the design sessions created a space wherein "open secrets" were spoken. Despite this, there also moments where ECE's recurring gender issues were made apparent through the design session participants. In sum, power dynamics can both aid and change design efforts.

Tension #3: The design process fostered skepticism about affecting ECE culture and optimism about individual change efforts in ECE.

As noted by Godrey [17], Lord et al., [29], and Jesiek and Jamieson [16], engineering cultures like ECE are deep-rooted and well-defined. As Jesiek and Jamieson note, this is due in part to "prevailing norms related to curricula, pedagogy, and professional issues [that] are often deeply entrenched, as well as increasingly outdated and resistant to change" [16, p. 4570]. Due to the intractability and established nature of the ECE culture, some participants described feeling skeptical of the design sessions' ability to impact organizational change while simultaneously noting ways that they were actively engaged in creating and adopting inclusionary practices on an everyday basis.

An example of participants' skepticism can be seen in the following excerpt from Christy. In the excerpt, Christy refers one of the prototype solutions for change in ECE: a junior-level professional development seminar for ECE undergraduates. This solution grew out of students' discussions about gaps in their D&I educational experiences in ECE. Christy describes her skepticism in the following way:

> It's easy to talk about diversity and inclusion, but what kind of changes will be done? So, what changes will be made to the 200, 300, 400 seminars? Will bias training be provided? I think it's pretty simple to do training online, like the implicit bias tests and just education like that. I don't know how effective online training is, that's not something we talked about. But could that kind of stuff be done to TA's and professors...I'd like to see that there's someone thinking about it, but I'm skeptical on what kind of actions will be taken.

Inherent in Christy's statement was the skepticism of changing the ECE culture. She notes that "It's easy to talk to about diversity and inclusion," but where are the actual meaningful changes in ECE? These types of reflective statements appeared throughout other interviews. For instance, Eula noted that efforts like the junior-level seminar needed to consider campus partners to be successful as change "remains to be seen." Referring to her role on campus, Eula cautions that the prototypes pertaining D&I efforts in ECE classes ought to utilize campus networks to encourage sustainability:

> That's a longevity thing. It's a matter of really having some way of assessing that over time, so that would be interesting to see with your TA classes, with [the junior-level

> class]. That's where you will, I think [pause] Again, I would work with [campus partners] on designing assessments.

To both Christy and Eula, change within ECE because of the design session prototypes required different ways of addressing and reconceptualizing professional formation; however, there is a doubt in the ECE as to whether large-scale, institutional change can occur in part because of the culture.

Others noted that the design session participants were not representative of ECE, which impacted both discussions and prototypes. Almost all the interviews noted the lack of representation from various groups of people. Arguing that a more diverse group of would have generated different perspectives on D&I issues within ECE, Eula noted, “I think the only thing is it wasn't diverse enough, the perspectives that were in there…areas that are considered under-represented or folks that represent those under-represented [pause] like culture centers or folks that work in those areas.” Others like Cordelia observed that the design session participants were missing key demographics from the undergraduate program: “I think getting more males would be important. Possibly more international students as well.” This was an important observation as the women participants were keenly aware that there was only one male, undergraduate student from the ECE program. The absence of these voices is best summed in the following interview excerpt: “If you don't have the voices there, you don't know what's missing, and it's hard for us to [pause] You can't really know what that is until you get it from them.”

Contrary to the uncertainty regarding the larger change possibilities within ECE, several participants noted that the design sessions sparked their own critical consciousness about D&I issues in ECE. That is, because of their participation in the design sessions, participants’ understanding of both diversity and inclusion were deepened as they became more aware of real-life D&I issues in ECE. The role of individuals’ stories and willingness to talk openly about social class issues was eye-opening for all of the interview participants. However, this example was but one of many that were mentioned. For instance, Christina shared that the design sessions served as a reminder that diversity and inclusion goes beyond what she called, “visual diversity.” Christina recalled listening to others talk about their own experiences and described it as,

> Eye-opening to see that diversity's not only visually defined, but also location-wise defined. Even the background of every single person. How they were raised. In order to say, "Yes, I am diverse," you don't need to have a chilling childhood to say that, "Yeah, I went through all of this, therefore I am diverse." That was really good.

Others discussed how the design sessions deepened their understanding of diversity and inclusion through an intersectional gendered lens where race and ethnicity also impact women’s experiences. Claudia described moments where she reflected on her leadership role within the Women in ECE student group. Because of the design sessions, she felt it important to recruit “women of other backgrounds or experiences” to the Women in ECE organization and its events. The design sessions offered opportunities to expand Claudia’s own understanding of the interconnections between culture and gender and served as a key way that inspired and informed

the Women in ECE recruitment efforts and programming during her time as leader. Sentiments likes Claudia's were also shared by others.

The critical consciousness that the design sessions cultivated for many of the participants also inspired participants to adopt micro-level change strategies to create inclusion in ECE. That is, they took it upon themselves to find ways to practice inclusion in and throughout ECE. Cordelia noted that the design sessions encouraged her to interact more with international students. Christy described that the design sessions were useful in building relationships with faculty mentors who seek to recruit more women into research groups. Finally, Christina, an alumna of the undergraduate ECE program, shared that the design sessions prompted her to find ways to take an active mentoring role with ECE students:

> …I think there's such a big gap and disconnect between how things are set up on an industry level. I think that definitely it was good for me to be able to possess that information and then see, "What can I do from my position here and how can I help, hopefully, bridge the gap at one point or another?"

Key Takeaway from Tension #3. Stakeholder diversity matter. On one hand, attempts at representation offered some participants (e.g., students and faculty) an experience to interact with and understand a variety of perspectives and issues that impact the ECE culture. Conversely, the lack of representation of (1) majority stakeholders (e.g., white, male students) and underrepresented minorities potentially limited the scope of understanding D&I issues in ECE. The design sessions seemed to promote individual-oriented strategies for change in ECE. Absent in the participants' descriptions of these efforts were explicit mention of how they might impact the broader ECE culture.

Discussion

Despite the facilitators' expertise in design, challenges emerged in attempting to enact change in the ECE School's culture using design thinking processes. Our analysis exposed three tensions regarding the effectiveness of design thinking toward addressing D&I issues in ECE that emerged as participants reflected on the design sessions and their role in enacting change. The presence of these tensions demonstrated the possibilities to explore boundaries of thinking about, understanding, and framing wicked problems [12]. Tensions also provided necessary insights into the potential cultural boundaries wherein change efforts become uncomfortable and there is a potential challenge toward existing cultural assumptions about what is and is not ECE. As such, our paper and study focused on the effectiveness of design in cultivating inclusionary change in an ECE culture that promotes traditional, organizational cultural dynamics (e.g., masculine orientation, linear thinking, and conventional approaches to problem-solving). Our study revealed a variety of reactions that serve as a starting point in highlighting the effectiveness of design thinking in organizational change efforts in engineering disciplines in three key ways.

First, our study shed light on the possibilities of change efforts led by novice designers. As Deininger, Daly, Sienjo, and Lee note, "Novice designers often differ from those of experts in key areas such as problem scoping, depth and breadth of information sought, iteration and time

spent during individual phases, and general design strategy" [30, p. 27]. Even though engineers do design as a part of professional practice, our study uncovered examples wherein participant designers appeared to lack the full understanding of design, design thinking, and how to utilize various aspects of the design process to address wicked problems like D&I issues. At times, their apparent uncertainty emerged through the three tensions uncovered in the interviews. There were simultaneous moments of confusion and clarity about the design process, as participants shared comments about the usefulness of repetition and iteration in the problem-scoping. Crismond and Adams offered, **"**Many designers, particularly novices, find it challenging to think divergently and get trapped in characteristics of known solutions" [18, p. 755]. Whereas traditional approaches to tensions in organizations would try to minimize these dynamics, we argue that tensions are a starting place for novice designers. That is, tensions offer and create important reflective practices that help to not only build important design skills for managing uncertainties in the design process, but the larger design thinking process provides a framework and toolkit to more deeply scope potentially wicked problems.

Second, our study provided emerging insights into the use of a framework that is helpful in starting conversations that may challenge existing and traditional notions of engineering. Dym argued that design is very different from traditional ways that engineering is taught and learned; design ought to be leveraged to "help students understand that much of what they need to know is not just a set of formulas" [4, p. 147]. Tension #2 acknowledges the utility and messiness that emerges when we consider different forms of language in sharing and naming experiences that are a central part of individual's engineering experiences. That is, personal stories and empathy became significant and relevant data to understand complex issues (e.g., Credence's example of financial insecurity). Thus, in our study, participants began to understand how wicked problems like D&I issues are and can be viewed as engineering design problems using design language. To that end, our study developed both a structure (e.g., the design curriculum) and tools (e.g., activities, conversation started, and a shared language) that can be leveraged and utilized in conjunction with existing engineering knowledge to address complex socio-technical issues.

Third, despite developing a structure that brought together various stakeholders, the tensions offered a starting point in managing and leading the change efforts within ECE. As stated, participants were both skeptical and inspired to enact change within the ECE culture; however, the individual-orientation toward change can only go so far. As Lee and Evans describe,

> Within traditional development projects, design has been fixed upon time-dependent, solution-focused, and tangible project outcomes. Such activities may result in innovative and creative solutions, but they may also fall short of connecting with organizational cultural change. Without continued organizational support, the use, implementation, and ultimate effectiveness of design are limited [31, p. 74].

Even with a seemingly diverse representation of stakeholders, the participants of the design sessions lacked structural influence and capital to enact broader, institutional change—that is, the sessions were comprised of students, faculty, and administrators. This is an important observation for two reasons. First, drawing upon Lee and Evan's assertion, limited connection to departmental leadership (and support) in addressing both curricular and cultural D&I issues in

ECE may contribute to the continued wicked problems in ECE. That is, efforts to create inclusionary change in ECE may be limited, continue to exist at micro-levels (e.g., individuals), or even backfire and further institutionalize D&I issues. Additionally, the lack of organizational support continues to sequester D&I issues as not central to engineering practice and professional formation. Second, the composition of design sessions matters in the prototypes that were generated. The voices that were present, while important, were not necessarily representative of demography and status in ECE. That is, when the absence of organizational leadership is felt, change continues to be located at individual levels as participants feel and perceive their lack of agency to enact structural change.

Conclusion

Given our study's focus on the effectiveness of design thinking, we argued that design can be effective in cultivating organizational culture change under certain conditions (e.g., proper stakeholders, organizational support, and a framework through which to enact change). That is, an amenable organizational culture matters in enacting change. Absent these conditions, change efforts are limited. Our study provided a glimpse into the disciplinary and cultural realities of engineering programs—that is, the tensions emerged as result of attempts to change a distinct and enduring ECE culture. Our study shed light on the reality of the ECE Culture, wherein support for "engineering as design" is not a reality. In our context, the participants of the design process frequently referred to the ECE culture in terms of the prevailing "engineering as science" paradigm, which situated engineering learning as solely technical (privileging math, science, and technology courses). In the ECE culture, our study further revealed that design and design thinking was not integrated, supported, or central to the culture. To that end, the tensions showcased that the "engineering as design" paradigm that Dym [4] and Dym et al. [5] and others called for was absent as this paradigm deeply contextualizes the integrated socio-technical issues through design, which include being able to address wicked problems. Our study found that that the effectiveness of design thinking perspectives may be limited in the short term given lack of adequate support, but sheds light on the necessary long-term strategies that are essential for sustained inclusionary cultural change.

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