Exploring Diversity and Inclusion in the Professional Formation of Engineers through Design Sessions

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***Abstract*— This Research Work-in-Progress paper builds on previous literature related to the professional formation of engineers and issues pertaining to diversity and inclusion within engineering though a comparative analysis of two different disciplines. These issues are complex, interrelated and challenging to untangle, and thus require innovative strategies to explore them. Our larger study utilizes design thinking with an embedded mixed-methods research approach to investigate foundational understandings of professional formation and diversity and inclusion in engineering. Herein, we describe preliminary findings from co-design sessions we conducted in Biomedical Engineering (BME) and Electrical and Computer Engineering (ECE) at Purdue University. We compare the design solutions generated by stakeholders and discuss insights regarding the unique contexts and needs of each program, as well as the impacts of the different activities and contexts of the design sessions themselves.**

Keywords— Professional Formation; Design Thinking; Diversity and Inclusion

I. Introduction

Studies have shown that although students are typically well-prepared for the theoretical and technical aspects of their work, they often lack an integrated socio-technical understanding of engineering and thus are unprepared for the complex realities of professional practice [1-4]. This finding is not surprising as the values and perceptions of engineering as communicated by most educational programs in engineering privilege technical knowledge and significantly lack in diversity (representation) and inclusion (integration of different perspectives, values, and ways of thinking and being engineers). These challenges facing engineering education, especially those related to diversity, require us to understand the aspects of students' professional formation that include not only what knowledge and skills they develop, but also include the development of perceptions of engineering practice and understandings of engineering identity (i.e., what it means to be an engineer) [5-8]. These issues are complex, interrelated, and averse to simple solutions. Put differently, these problems are "wicked" ones that require engaging broad perspectives and innovative strategies to simultaneously understand and spark the deep transformations needed within the engineering discipline.

Camilus described, "A wicked problem has innumerable causes, is tough to describe, and doesn't have a right answer. …Not only do conventional processes fail to tackle wicked problems, but they may exacerbate situations by generating undesirable consequences" [9, p. 1]. One possible way to attempt to mitigate these problems is with a human-centered design thinking approach [10-14]. A human-centered design thinking approach enables a deeper exploration and understanding of these issues and how they occur within a specific context. More importantly, a design thinking approach brings stakeholders together to center their experiences and insights as vital to understanding underlying issues which subsequently allows them to enact local change. Design thinking approaches have been successful for cultural and organizational transformations through the illumination of participants' contradictory knowledge, insights and experiences, which become necessary in creating and implementing potential solutions [15-19]. Thus, we have undertaken a design thinking approach to explore foundational understandings of professional formation and diversity and inclusion in engineering [20].

Although the goal is to eventually study these issues on a broader scale, we have begun with a smaller, local context: the School of Electrical and Computer Engineering (ECE) and the Weldon School of Biomedical Engineering (BME) at Purdue University. These schools share similarities with some common coursework and faculty, but also provide contrasts such as in gender diversity, as BME's undergraduate population is 44% female, where ECE is 15% female. And although BME has slightly more underrepresented minority students (7% versus 6%), 59% of BME undergraduate students are white, versus 40% for ECE since 35% of the undergraduate population in ECE are international students, which contrasts with 12% in BME. The size of the schools varies dramatically as well. Whereas BME has approximately 275 students, ECE has approximately 1400 undergraduate students (close to 20% of the total population within the College of Engineering).

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II. Study Design

The overall research project is organized around three phases of design - inspiration, ideation, and implementation [21]. The inspiration phase of the research study included gathering survey, interview, and observational data from key stakeholders (students, faculty, staff, alumni, and administrators) from ECE and BME at Purdue University.

The survey data were collected from ECE and BME undergraduate students (N = 134 ECE and 31 BME undergraduate students). The survey included items related to identity and professional formations from the Academic Pathways of People Learning Engineering Survey (APPLES) and the Engineering Identity Survey (EIS) [22], items assessing students' perceptions of their schools' climate of inclusion and sensitivity to diversity, overall climate, and "unwritten rules", educational experiences, and demographics. To provide explanatory depth to our survey data, we also conducted 24 semi-structured interviews with faculty, staff, and administrators (FSA) in BME (N=12) and ECE (N=12). Additionally, we conducted 33 interviews of current or former students (N= 18 BME and 15 ECE).

Although the analysis of the data collected from the inspiration phase gave us insight into some of the underlying issues surrounding diversity, inclusion, and professional formation within BME and ECE, we also wanted the stakeholders to work through the ideation phase to further illuminate, refine, and understand the core issues and needs of each school to inform their design of the prototype solutions. The implementation phase of this design thinking approach will involve iterating on the prototype solutions generated during the ideation phase, and beginning to apply them to address issues related to professional formation and diversity and inclusion within each of the schools.

For both BME and ECE, stakeholder participants were recruited to participate in the designs sessions through an email invitation sent by the research team. Some participants previously participated in our survey and interview studies; others were recruited based on interest and word-of-mouth from other participants. All research protocols involved in this study were approved by the IRB of Purdue University.

Next, we describe the strategies that were employed in each of the design sessions, the design solutions that were generated, the preliminary findings and insights that have emerged through this process, as well as proposed future research.

III. Design Sessions

A. Biomedical Engineering (BME)

The design sessions in BME consisted of six sessions over the course of several weeks. Participants in the design sessions consisted of 18 representative stakeholders including students, faculty, and staff members, including individuals from the advising office and lab courses. Activities in the design sessions were facilitated by members of the research team. In Design Session 1, we asked participants to complete Professional Journey Maps individually. The Professional Journey Map prompted participants to chart their own personal and professional career journeys along a timeline; attention was given to moments during the participants' lives that elicited both positive and negative emotional responses. These moments and career journeys were then shared in small "mixed" groups (faculty, staff, and student in group together). The discussions often alluded to insights about their BME professional formation process and identity, as well as aspects of their personal journeys and identities. Finally, participants were invited to share their personal motivations for contributing to the Design Sessions and why they thought their involvement was important. To do so, we asked them to reflect individually on stickey notes and then share in small groups: 1) Why are you here? 2) What does Diversity mean to you? 3) What does Inclusion mean to you? and 4) Who is not here?

In Design Session 2, we created and discussed word cloud representations of their responses to the reflection questions on Diversity and Inclusion from Design Session 1. Next, we asked participants to reflect on the desired and current states in relation to Diversity and Inclusion in BME. After each session, participants received a copy of the session slides and were asked to complete outside tasks for the next Design Session. For "homework", participants completed culture maps [22] which allowed them to reflect on and brainstorm various aspects of the BME organizational culture. These were discussed in small groups at the beginning of Design Session 3, after which participants created a common culture map for their small group. Building off the common culture map, participants identified approximately five target issues they felt were feasible, prominent, and relevant to the goals for Design Session 4. Specifically, they responded to the following questions: What issues were presented that you feel are a priority? What issues address matters of diversity and inclusion in BME? What issues can we feasibly address?

During Design Session 4, participants individually generated approximately five target issues that they thought were feasible, prominent, and relevant to goals. Participants placed these issues along one Professional Journey Map continuum, grouping similar issues together (themes), and voted for their top three issues using colored dots. The top three issues/themes identified by the group were: Curricular Content, Mentorship, and Identity. The participants chose which issue they would like to explore further, then engaged in abstraction laddering [23] to uncover underlying assumptions of the top three issues. As homework, participants completed a design challenge exercise worksheet [24] for their identified issue.

During Design Session 5, participants met in their same small groups (Curricular Content, Mentorship, Identity) to identify and synthesize the key issues and possible solutions related to their topic. Each small group presented their issues to the larger group, trying to connect to other issues of the solutions of the other groups. As homework, participants were asked to email one specific recommendation for the implementation team intended to increase diversity and inclusion in BME that addressed the three identified key issues of professional formation. Four recommendations emerged out of this exercise. Finally, in Design Session 6, participants created design specifications for the recommendation of their choosing. The specifications included responses to the

following questions: What need(s) is this addressing? How does this affect Diversity and Inclusion? What are the user requirements? What are the design specifications, specific actions, and/or components of this proposal? What can be leveraged? What are constraints/blockers? What does success look like for this recommendation? What ways can we evaluate or measure this success? Each group presented their recommendations and specifications to the larger group.

B. Electrical and Computer Engineering (ECE)

The Design Sessions in ECE consisted of six sessions over the course of a semester. Participants for these design sessions included 21 ECE faculty, undergraduate and graduate students, alumni, and staff members, including individuals from the advising office and lab courses. In addition, a staff member from the university intercultural center participated. Activities for the sessions were facilitated by members of the research team. It is important to note that whereas the BME sessions were 120 minutes, due to participant availability, the ECE Design Sessions were 90 minutes. Because of this, the use of "homework" and reflection became more critical to engaging participants in reflection about design session experiences.

Like the BME Design Sessions, ECE participants also completed a Professional Journey Map in Design Session 1; however, the Professional Journey Map was modified to include more directed prompts about participant's thoughts and feelings. Once completed, these were shared in small, mixed groups of faculty, staff, and student participants. As "homework" for Design Session 2, participants were asked to reflect on their personal experiences in their design notebooks, read an article pertaining to institutional barriers within the engineering discipline [25], and to consider which voices were not represented in the ECE Design Sessions.

Building off Design Session 1, Design Session 2 focused on discussing and deepening participants understandings of diversity and inclusion issues. Time was spent reflecting on their career journeys and their reactions to the assigned journal article. After the discussion, participants were then asked to group themselves into self-selected identity groups (i.e., women, men, international, and missing voices), and create a prototypical journey map of these groups of people. In groups, participants collaboratively framed issues within ECE pertaining to diversity and inclusion and professional formation from their identity group's perspectives.

In Design Session 3, the participants spent time discussing preliminary results from the interview study during the research team's ideation phase. The discussion highlighted tensions within ECE about student and faculty experiences, microaggressions that occurred in and out of the classroom, and pressing issues within ECE [26]. These three discussion threads converged as participants began to articulate and frame a design challenge that would guide the group toward developing a prototype solution within ECE. The initial drafts of the design challenges were then collected, synthesized, and sent to the participants for review before Design Session 4. Based on the design challenge drafts, participants were asked to reflect on the following prompts for homework: How do these challenges impact diversity and inclusion and the professional formation of electrical and computer engineers?

During Design Session 4, participants discussed their thoughts on the design challenges. In a group discussion, participants responded to the following questions about the design challenges: What is the relationship between these challenges? How are they related to (1) diversity and inclusion and (2) professional formation? What do we want to tackle first? These questions offered participants an opportunity to further refine and merge similar challenges together. In mixed groups, participants began engineering prototypical solutions to the challenges. They were challenged to consider the subcomponents of the solution, identify potential problems with their solutions, and strategize different contexts of implementation. As homework for Design Session 5, participants were asked to review the refined design challenges and respond to the following questions: What need is this addressing in the design challenge (diversity and inclusion; the professional formation of engineers; both)? Where would students meet this solution during their journey? Who are other stakeholders in this journey? What underlying knowledge, assumption, or understanding about ECE is revealed in this solution? What else should we be asking you?

Whereas Design Session 4 resulted in refinement of several design challenges, Design Session 5 focused on further consolidation of challenges. Through discussion during Design Session 5, the participants consolidated the design challenges into three primary prototype solutions (TA training, a professional development course for undergraduates, and an integrated socio-technical redesign of the curriculum). Design Sessions 5 and 6 were devoted to small groups developing implementation plans for each of the solutions, which were presented to the larger groups after Design Session 6.

IV. Design Solutions

The following section details the solutions that were developed by each of the programs during their respective design sessions. Four solution ideas emerged from the BME design sessions.

1. Develop a multi-pronged, active outreach program, especially for under-represented groups, including traditional American minority communities and military veterans, to create a community that talented people of all backgrounds and future paths will want to join.
2. Develop a more explicit and shared understanding of professional formation and school identity in BME that is inclusive of the diversity of both the people (students, staff, and faculty) of the BME community and the professional activities in which they engage.
3. Develop a multi-tiered, comprehensive mentorship program involving students, grad students, alumni (specifically minority alumni), faculty and staff with both formal and informal elements, targeting different student's needs and goals as they change with progression from pre-college to post-graduation and giving students

more support while they go through professional formation in biomedical engineering.

4. Develop an assessment program for diversity and inclusion that identifies and annually evaluates key elements of community interactions and educational activities that contribute to enhanced diversity and inclusion both inside and out of the classroom.

Three major proposals emerged from the ECE Design Sessions, although each of the proposals combined multiple aspects:

1. Develop Teaching Assistants (TAs) Training modules to address two converging needs within ECE: (a) cultivating stronger, more inclusive student interactions; and (b) providing teaching assistants (TAs) with training to adequately address intercultural and team dynamics within lab and lecture spaces. This would be achieved through a three-pronged approach: (i) Provide TAs with appropriate instructional training to address social/intercultural issues within lab spaces; (ii) Leverage opportunities within labs to further embed socio-technical learning by requiring student lab reports to include a reflection paragraph on their teamwork, roles, strategy for completing the reports, and reflecting on success and missteps throughout the labs in light of professional expectations for teamwork; (iii) Create opportunities for students to learn to interact with one another with respect, curiosity, and value for diverse views within the large lecture halls to create a more connected ECE community.
2. Develop a junior level seminar to address a gap in the ECE professional development seminars. It is needed to help: (i) students prepare for senior year activities such seeking full-time employment positions and/or applying to graduate programs, (ii) provide a scaffolded learning experience in which they can develop important communication and intercultural competency skills, and how to work more effectively on diverse teams; (iii) provide an opportunity to understand the struggles and challenges that others experience so that students know they are not unique, and also how to overcome them.
3. Create curricular support for multi-disciplinary and vertically-integrated "Design Threads" to address a lack of authentic design experiences, especially in the Electrical Engineering (EE) program. The threads would provide opportunities to work on project teams in different design and research contexts. The project teams will be mentored by faculty and industry advisors to help students make connections between knowledge they are gaining in their courses to the practice of engineering and develop more integrated socio-technical understandings of engineering. In addition, students will have the opportunity to develop the broad set of technical and professional skills including teamwork, leadership, project management, ability to identify and learn knowledge needed for their work, and interpersonal and technical communication skills.

V. Discussion

The results of the design sessions reflected the unique contexts of both the programs, as well as the design sessions themselves. The different demographics, organizational cultures, and unique issues of each of the programs influenced the ideas that emerged. For example, in ECE, the size of the program coupled with the large international population within the School provided unique challenges in developing solutions that addressed a highly diverse undergraduate population. The proposed solutions articulated and integrated diversity and inclusion *and* the professional formation of engineers in interactional ways from lab spaces, classrooms, and curricular redesign to better prepare engineers for professional practice. Conversely, in BME, the solutions adopted a broader approach that focused on cultural transformation through recruitment, assessment, and mentoring practices.

For both programs, there was concern about whose voices and experiences were not represented in the departments and in the design sessions, including especially people from underrepresented populations. However, it was noted that this is a concern more broadly in the college and at the university, and although a few strategies were identified that potentially could address this lack of diversity in the programs individually, efforts simultaneously needed to be directed at both the college and university levels.

VI. Future Work

Future work includes formal analyses of the artifacts from the design sessions, including post-design session interviews of the participants. In addition, research will continue to follow the implementation of the solutions generated via the design sessions. Also, research continues to explore the impact that the design sessions on the climate of each of the programs related to diversity and inclusion. We have anecdotal evidence of conversations and different mindsets that emerged as a result of the design sessions. Another area of research adopts a crystallization approach that examines the multiple methodologies utilized throughout this project [27]. Crystallization,

> combines multiple forms of analysis and multiple genres of representation into a coherent text or series of related texts, building a rich and openly partial account of a phenomenon that problematizes its own construction, highlights researchers' vulnerabilities and positionality, makes claims about socially constructed meanings, and reveals the indeterminacy of knowledge claims even as it makes them [27, p.4].

Moreover, Ellingson's methodological approach offers our research team an opportunity to give voice to our participants in new ways, which is important considering the variety of data collected (i.e., survey, interview, observation, video). More important within this approach, though, is the utility of examining the research team's reflexivity and multiple roles as researchers, facilitators, and participants throughout the design process. We hope to extend our work to the College level to explore the recruitment issues that were identified in the ECE and BME design sessions.

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