Understanding the Professional Formation of Engineers through the Lens of Design Thinking: Unpacking the Wicked Problem of Diversity and Inclusion

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Introduction

Three broad issues have been identified in the professional formation of engineers: 1) the gap between what students learn in universities and what they practice upon graduation; 2) the limiting perception that engineering is solely technical, math, and theory oriented; and 3) the lack of diversity (representation of a wide range of people) and lack of inclusion (incorporation of different perspectives, values, and ways of thinking and being in engineering) in many engineering programs. These are not new challenges in engineering education, rather they are persistent and difficult to change. There have been countless calls to recruit and retain women and underrepresented minority group members into engineering careers and numerous strategies proposed to improve diversity, inclusion, and retention, as well as to calls to examine socio-technical integration in engineering cultures and education for professional formation.

Despite the changes in some disciplinary profiles in engineering and the curricular reforms within engineering education, there still has not been the deep transformation needed to integrate inclusionary processes and thinking into professional formation. In part, the reason is that diversity and inclusion are still framed as simply "numbers problems" to be solved. What is needed instead is an approach that understands and explores diversity and inclusion as interrelated with the epistemological (what do engineers need to know) and ontological (what does it mean to be an engineer) underpinnings of engineering. These issues are highly complex, interconnected, and not amenable to simple solutions, that is, they are "wicked" problems. They require design thinking. Thus our NSF-funded Research in the Formation of Engineers (RFE) study utilizes a design thinking approach and research activities to explore foundational understandings of formation and diversity and inclusion in engineering while addressing the three project objectives: 1) Better prepare engineers for today's workforce; 2) Broaden understandings of engineering practice as both social and technical; and 3) Create and sustain more diverse and inclusionary engineering programs.

The project is organized around the three phases of the design process (inspiration, ideation, and implementation), and embedded within the design process is a longitudinal, multiphase, mixed-methods study. Although the goal is to eventually study these objectives on a broader scale, we begin with a smaller 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 as BME's undergraduate population, on average for recent semesters, has been 44-46% female, where ECE has been 13-14% female. Although BME has slightly more underrepresented minority students (7-8% versus 5%), approximately 60% of BME students are white, versus 40% for ECE. It is important to note that Purdue's School of ECE offers B.S. degrees in Electrical Engineering (EE) and Computer Engineering (CmpE), which reflect unique disciplinary cultures. Additionally, the schools differ significantly on undergraduate enrollment. The BME enrollment was 278, whereas ECE's enrollment was 675 in EE and 541 in CmpE[1].

In this paper we describe the background literature and the research design, including the study contexts, target subject populations, and procedures for quantitative and qualitative data collection and analysis. In addition, we present the data collected during the first phase of the research project. In our poster, we will present preliminary analysis of the first phase data.

Background Literature

A number of studies have shown that the current engineering education system adequately prepares students for the theoretical and technical aspects of their profession but inadequately equips them for the complex realities of professional practice[2-5]. At the same time, the values and perceptions of engineering often communicated in engineering education are singularly technical and not human-centered in an inclusionary manner. Research[6,7] has shown values such as a quantifiable reality, mathematical reasoning, and objectivity as ingrained assumptions within engineering cultures[8]. Furthermore, research on engineering identity speaks directly to the ontological question--*what does it mean to be an engineer*? There have been numerous social scientific[9-11] and social cultural[12,13] perspectives that have explored identity in general and engineering in particular[14-17]. These perspectives address the complex processes by which individuals, groups, institutions, and cultures produce and reproduce identity formations[18-20]. Exploring engineering identity addresses the gap between student learning and practice as well as core values and assumptions common to engineering. These dimensions of engineering identity, altogether, create a space for addressing the complexity of professional formation including diversity and inclusion.

The ontological question of *being* is related to perceptions about the nature of engineering practice, as summarized by Stevens and O'Connor[21] when they contend that full understandings of engineering as taught and practiced will not be achieved until there is attention "not just to what people learn and know but also to who they are and what is their place in the world among their consociates *as engineers*, both within their local professional networks and within social life more broadly" (p. 126). Therefore, the challenges facing engineering education, especially those related to diversity, go beyond developing knowledge and skills, but also include perceptions of engineering practice and understandings of engineering identity (i.e., what it means to *be* an engineer) that situate the social and the technical as one and the same. Understanding salient dimensions of an engineering identity as such is critical for professional formation as well as for recognizing possible boundaries for inclusion.

Unpacking engineering's core values and assumptions of engineering identity provides an opportunity for engineering educators to identify places to create more inclusive environments. Students' experiences of engineering within their undergraduate education shape their understanding of the nature of the work done by engineers, the skills and knowledge that are valued and needed in engineering, and whether these things align with their personal identity and values. These aspects of engineering identity are prime territory for developing an inclusive educational environment that acknowledges and values diverse perspectives. Specifically, Trevelyan[22] speaks to the salient social and technical values found in engineering. He argues "there is a tendency among engineers to define 'real' engineering in terms of the technical 'nuts and bolts' and scientific and mathematical labor, thereby locating the social aspects of heterogeneous engineering outside of 'real' engineering (cf. [22])" (p. 127[21]). Separating the "technical" and "social" as such limits any possibilities for heterogeneous views of engineering, where in fact the social and technical can be inextricably tied together. Godfrey[8] found that in addition to making this distinction, there is a "devaluing of content or subject areas that were seen as 'easy' or 'soft'. (p. 442)" Positioning technical characteristics as "real engineering" inhibits engineering students from identifying with the social aspects inherent in engineering which might be where their passions are focused. For instance, BME has displayed radical differences from other engineering disciplines in terms of rates of undergraduate female participation. Studies[8,23] have found that female students identified more with BME due to the salience of social characteristics such as working and helping "real" people. Thus, embracing both social and technical dimensions of engineering identity is critical for creating diverse and inclusive environments. In sum, addressing what it means to be an engineer – specifically, by bringing social dimensions into the core of engineering – helps engineering educators in two key ways. First, integrating the social and technical shifts notions of diversity and inclusion from a singular problem that needs to be "fixed" into framing diversity and inclusion as practices. Evident in practice, social and technical dimensions are in constant dynamic and interactive flux and thus should be conceptualized as processes rather than as two distinct and static entities. Second, a more comprehensive view of engineering identity affords more experiences with which diverse individuals can identify[20] and feel welcome as participants (i.e., "engineering is for me, too."). Similar to the BME example, an engineering identity that values both social and technical dimensions presents more values and premises with which individuals can identify thus leading to more "whole-minded engineers."

Research & Development Plan

This NSF-funded RFE study utilizes a design thinking approach to develop solution(s) that address our three interrelated objectives: **to better prepare engineers for today's workforce, to broaden understandings of engineering practice as both social and technical, and to create and sustain more diverse and inclusionary engineering programs.** We are involving key stakeholders from the School of Electrical and Computer Engineering and the Weldon School of Biomedical Engineering at Purdue University, including students, faculty, staff, administrators, and alumni in the research and design process to co-create solutions that can address the three interrelated objectives, as well as our research questions:

- **How might we make engineering more inclusive?**
- **How might we better prepare engineering graduates for practice?**
- **How might we use design thinking to address complex issues in engineering education?**

The project is organized around the three phases of the design process (inspiration, ideation, and implementation, see Figure 1) and addresses the goals and research questions in an integrated, participatory, and iterative manner. Thus, our **specific outcomes** include:

1) An understanding of the similarities and differences of the culture, ontologies, and epistemologies of ECE and BME engineering programs
2) An understanding of how Outcome 1 impacts the diversity and inclusion of the disciplines

3) An understanding of how Outcomes 1 & 2 impact professional formation within the disciplines
4) A process of applying design thinking to complex issues in engineering education

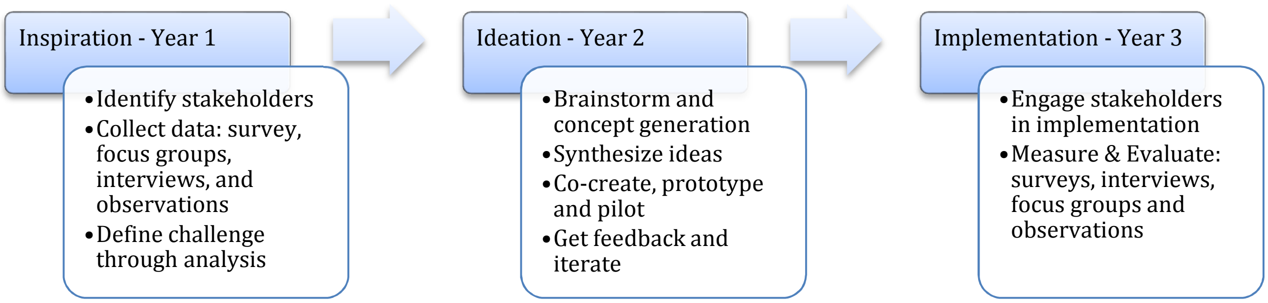

Figure 1. Design Thinking Process adapted from IDEO[24]

Study Overview

Participants: Consistent with design thinking and our analysis of inclusionary professional formation as a wicked problem, we are including a wide and diverse group of stakeholders—students and faculty, staff, and administration (FSA), and alumni—from each discipline in all aspects of the design and research activities. Furthermore, we are focusing on including women, underrepresented minorities, people with disabilities, first-generation students, and those from low socio-economic backgrounds in the stakeholder groups, as they are the ones most often impacted by the lack of diversity and inclusion.

Study Design: Embedded within the design process is a longitudinal, multiphase, mixed-methods study. A mixed-methods approach is "premised on the idea that the use of quantitative and qualitative approaches in combination provides a better understanding of research problems than either approach alone"[25] (p. 18; see also Creswell and Clark[26], Ch. 3), including use of multiple and complementary sources of evidence throughout the process, and leveraging the strengths of multiple research paradigms.

Data Collection: Table 1 summarizes the data collection plan through the phases of the design process. In each phase, we will collect data from various stakeholders from Electrical and Computer Engineering (ECE) and Biomedical Engineering (BME) that inform both our research questions as well as the design and implementation of the solutions to achieve our objectives. Each measure is described in detail below.

Table 1. Data Collection Plan Sources by Phase and Stakeholder Group

Design Phase	Students	Faculty/Staff/Admin (FSA)	Alumni
Inspiration	• Surveys (N=165 BME & ECE): Demographics, Professional Identity and Formation Survey, Measures of diversity and inclusion • Interviews (N=12 ECE, N=18 BME) • Observations	• Interviews (N=12 ECE, N=12 BME) • Observations	• Survey (Target N=200 BME & ECE alumni who graduated between 2007 and 2016)

Ideation	• Brainstorming • Co-creation/prototyping sessions for both solution and implementation • Informal and Formal Feedback Sessions • Capabilities assessment	• Brainstorming • Co-creation/prototyping sessions for both solution and implementation • Informal and Formal Feedback Sessions • Capabilities assessment	• Brainstorming • Co-creation/ prototyping sessions for both solution and implementation • Informal and Formal Feedback Sessions
Implementation	• Surveys (Target N=150 ECE, N=50 BME): Demographics, Professional Identity and Formation Survey, Measures of diversity and inclusion • Interviews (Target N=15 ECE, N=15 BME) • Evaluation of the process	• Interviews (Target N=30 ECE, N=15 BME) • Evaluation of the process	
Institutional Data	• Demographics of undergraduate populations of ECE and BME	• COACHE Survey results for ECE and BME (2012 & 2015) • ECE Self-study Report	
Documents		• Departmental websites • Course syllabi	

Inspiration phase: The inspiration phase is focused on engaging with and gathering information from a broad and diverse set of stakeholders in both ECE and BME. The objective during this phase is to develop insights, perspectives, and understandings relative to views of diversity and inclusion, perceptions of social-technical integration, as well as the professional formation processes of the different disciplines. Findings from this phase will be used to identify the underlying design challenges that will be addressed, as well as contribute to foundational knowledge related to formation and diversity and inclusion.

Ideation phase: The goal of the ideation phase is to develop solutions *with*, not for, the representatives of the stakeholder groups. Design tasks in this phase will include brainstorming, developing a conceptual frame, prototyping potential solutions, getting feedback, iterating, and defining the point of view (challenge) to be addressed[27] for both the solution itself, as well as for the design of an implementation plan. The design tasks will also provide opportunities for data collection, as outlined in Figure 1.

Implementation phase: The implementation phase will involve implementing, measuring, and evaluating; that is, taking the information and insights gained from the inspiration and ideation phases and putting them into action. Although our survey data may enable us to detect change, it is possible that even if our processes are successful, we may not have statistically measurable changes. Even where we can observe that there have been behavioral changes and we would expect item and scale scores to reflect attitudinal change, the context will have changed meaning that the item may no longer mean what it originally did. In other words, if we move toward greater inclusion, then that becomes the new normal. So expectations for greater inclusionary practices are higher than they were prior to our initial data gathering. However, the interviews and focus groups will allow us to detect change insofar as we can mark differences in language choices, reported behaviors, and use of spaces that would indicate greater inclusion and collaboration. In addition, we will conduct an evaluation of the process itself, rather than only measurable outcomes aligned with our three goals. Capabilities assessments[27] will also be included in order to develop sustainable plans for implementing design solutions.

Data Analysis

Because design requires many different kinds of data to capture the messy and often unanticipated aspects of the design phases and processes, a mixed method approach enables us to: address our three goals; obtain different kinds of understandings, behaviors, and values; triangulate for richer data and findings; and bridge micropractices, meso or engineering discipline identities and priorities, and societal values, and cultural formations. Thus, the *quantitative* study data will be analyzed to examine within- and across-group comparisons using statistical techniques, such as, correlation, ANOVA, and MANOVA relationships. Additional analysis, such as, Multilevel modeling (MLM) will be conducted in order to simultaneously model individual-level and organization-level variable effects[28]. MLM accounts for the interdependence and hierarchal relationships between individuals whom are nested within organizations. In order to capture changes in processes, higher order process-based analysis such as Markov Analysis[29,30] can be used as well. These techniques identify temporal sequences and test empirical data to fit possible process models[28]. Other statistical techniques might also be employed depending on exploratory results. Ultimately, the goal of this analysis is to leverage the quantitative data to examine key associations between individuals, groups, and engineering departments.

The *qualitative* study data will be analyzed using a thematic analysis approach[31] to code for prominent themes following best practices across the six analysis steps recommended by Braun and Clark[32]: getting familiar with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and reporting results. This analysis method accommodates identification of themes both inductively and deductively[33]. It also allows for generation of novel insights, systematic study of similarities and differences in the data set, and multiple interpretive approaches (e.g., social, organizational, psychological)[32]. In short, thematic analysis is useful for obtaining general understandings in coherent patterns that, for studies of organizational culture, are considered integrated or unified cultural approaches (e.g., what it means to be an engineering professional across BME and ECE, particularly core ontological and epistemological understandings). To ascertain subgroup understandings, a differentiation lens to culture, identity, and professional formation contrasts ways in which the two engineering disciplines of BME and ECE are different from each other yet internally coherent, thus indicating variations in engineering themes, practices, and expectations. This second differentiation lens might also uncover subgroups within BME and ECE that are distinctive yet internally cohesive. Finally, the third cultural lens of fragmentation enables examination of paradoxical and multiple interpretations of socio-technical aspects, diversity and inclusion, and professional formation[34]. The fragmentation lens can indicate whose interests are served by the status quo and where and how new relationships can be made. These three lenses, drawing from but expanding upon thematic analyses and supplemented by observation and document analyses, provide a rich, multilayered approach to the context as would be appropriate for a design project on the professional formation of engineers and engineering.

The sections that follow are focused on the first (Inspiration) phase of the study, which include the student surveys and the faculty, staff, and administrator (FSA) and student interviews. In the poster session, we will present the needs that have been identified through the Inspiration Design Phase, which will include preliminary analyses of the student and alumni surveys and faculty and student interviews.

Preliminary Results

As mentioned previously, the objective of the Inspiration phase is to develop insights, perspectives, and understandings relative to views of diversity and inclusion, perceptions of social-technical integration, as well as the professional formation processes of the different disciplines. This is being achieved through the collection of a variety of data.

Data Sources Collected

Student Surveys: We have collected survey data from a targeted population of undergraduate students (N= 134 ECE and 31 BME undergraduate students, which represents 11% of each school). The student survey data serve two primary functions. First, this information provides insight regarding students' perceptions of their engineering discipline, diversity and inclusion, and engineering professional formation. Second, survey data serve as baseline measures in order to generate comparisons and document changes between the various constructs. The student survey consisted of the following categories of items:

- *Demographics*: Socio-demographic items (sex, disability status, ethnicity, citizenship status, family education background, socio-economic classification, year in school, and engineering discipline) and family history with engineering.

- *Identity & Professional Formation Survey*: Items from both the Academic Pathways of People Learning Engineering Survey (APPLES) and the Engineering Identity Survey (EIS)[35] that focused on identity formation, sense of belonging, perceptions of skills needed by and types of activities performed by engineers.

- *Diversity, Inclusion & Climate:* Items assessing students' perceptions of their schools' climate of inclusion and sensitivity to diversity, overall climate, and "unwritten rules"

- *Educational Experience:* Curricular and co-curricular experiences (e.g., pedagogical approaches and participation in learning communities, service learning, work experience that is engineering and/or non-engineering related), faculty interactions, how and what students learn formally and informally about being engineers, and students' perceptions of their relationships with faculty, staff, and peers were included.

Interviews: To provide explanatory depth to our survey data, we have conducted 12 BME FSA interviews, 12 ECE FSA interviews, and 30 student interviews (18 BME and 12 ECE current or former students). Student participants were initially purposefully sampled from our survey respondents to insure adequate representation of our populations of interest: women, underrepresented minorities, people with disabilities, and first-generation students. In addition, we are interviewing students who had left either BME or ECE and some who did not originally complete the survey. The interviews, for both FSA and students, are semi-structured and included questions related to the following categories:

- What it means to be a BME/ECE engineer?
- What sorts of knowledge is required in being a BME/ECE engineer?
- How students come to know about BME/ECE? (i.e., typical learning experiences)
- What is the disciplinary culture at each school?
- Perceptions of the diversity and inclusion climate within each discipline,

Additionally, the student interviews include:

- Students' perception of what sorts of activities they believe they will be doing in their engineering professions
- What learning experiences they feel have prepared them for a career in engineering.
- What role they believe diversity and inclusion plays in professional formation.
- Obstacles they have experienced or are experiencing in becoming the engineer they would like to be?

***Observations*:** Initial observations were conducted during the last two weeks of the spring 2017 semester. Observations are closely following the dimensions presented in both Schein[36,37] and Godfrey and Parker[5]. That is, we are giving close attention to surface level artifacts of culture (e.g., documents, daily practices, and behaviors) as well as to shared values and assumptions deeply embedded across groups and disciplines. Godfrey and Parker's[5] six cultural dimensions are helping to guide and situate these cultural assumptions across various settings. As complementary data, we are observing for consistencies and inconsistencies or contradictions in behaviors from themes uncovered in survey and interview data. We have conducted initial observations during disciplinary information sessions, courses, labs, and open collaborative spaces. These settings serve as opportunities to observe what values are presented and how these values are communicated and shared across groups. Observing the deeply held and often taken-for-granted cultural assumptions that exist within and across stakeholder groups. Observations will reveal how professional formation is shared, maintained, and reproduced within ECE and BME.

Alumni Survey: We identified a gap in our original data collection as it did not include the perspectives of recent graduates of the ECE and BME undergraduate programs. Thus we have recently implemented a survey that includes questions from the PEARS survey[38,39] related to perceptions of skills needed by and types of activities performed by engineers, types of experiences they participated in during their undergraduate education, and the extent to which they felt they were prepared for practice.

***Institutional Data*:** To further assess dimensions of culture within ECE and BME, we are collecting institutional data per discipline, such as basic demographic numbers of the ECE and BME undergraduate populations. We will have collected COACHE[40] (Collaborative on Academic Careers in Higher Education) survey results from 2012 and 2015 for both disciplines. Additionally, we are collecting school-specific documentation such as departmental websites, course syllabi, orientation information (i.e., orientation materials for faculty, staff, and students), and promotion materials for school programming/initiatives. Altogether institutional data will add further insight into the values and beliefs being promoted and communicated to stakeholders.

Future Work

The major goal of reforming professional formation of engineers requires new understandings about the complex and contradictory nature of the wicked problems of diversity and inclusion and social and technical integration in engineering cultures and education for institutional transformation. The new understandings from our research will delve into the epistemological and ontological core of how to think differently in engineering and how to do engineering and be an engineer in an increasingly globalized and rapidly-changing world. During the poster session, we will present the preliminary results from the Inspiration phase of the study and invite conference participants to provide feedback.

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