Intersections of Design Thinking and Perceptions of Success for Electrical, Computer, and Software Engineering Students

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Introduction

Engineering design thinking has become an important part of the educational discussion for both researchers and practitioners. Colleges and universities seek to graduate engineering students who can engage in the complex nature of combining both technical performance with design thinking skills. Prior research has shown that design thinking can be a solution for solving complicated technical and social issues in a holistic, adaptive way. However, little is known about how students make sense of their design thinking experiences and reconcile that into their perceptions of what it means to be a successful engineer. Without negating attempts already made to change course toward improvement, this reality must continue to be addressed with renewed enthusiasm if the benefits of design thinking are to be realized. Creating engineering academic environments that embrace and advance equity and inclusion should also embrace design thinking as a tool toward that goal. Doing so can serve as a way to create better learning environments for marginalized people as well as those who hold dominant identities because design thinking encourages team building and holistic, person-centered thinking.

As part of a five-year National Science Foundation REvolutionizing Engineering and Computer Science Departments (NSF-RED) grant, this study highlights the experiences of students engaged in a course which has been redesigned to enhance student development through design thinking pedagogy. This case study sought to understand how electrical, computer, and software engineering [ECS] students engage with design thinking and how that engagement shapes their perceptions of what it means to identify as a successful engineer.

The **research questions** for this study are:

1. How do ECS engineering students make sense of design thinking in an academic course setting?
2. How does design thinking in an academic course shape perceptions of what it means to identify as an ECS engineer?

Background

Scholars have suggested that for engineering students to be successful toward the completion of their degrees, and then later in their careers, developing an engineering identity is vital toward that goal[1,2]. The ability to do something successfully, or to establish mastery with a skill allows a person to feel "competent" at that skill. Such is a feeling universal to most people, not just engineers. Competency may not necessarily be cut-and-dry, however, as Walther, Kellam, Sochacka, & Radcliffe (2011) suggest a "complexity [among] the interactions between influences that lead to students' competence formation" (p. 720)[3]. Feeling competent – or prepared and able to do the work required, a sense of confidence – is vital to students' development of engineering identity[4,5].

Engineering design thinking has become an important part of the educational discussion for both researchers and practitioners. Recent academic conversations have suggested that implementing design thinking in the classroom can successfully encourage students to build their engineering identity. Design thinking can apply in any science. In the context of engineering is at once simple and complex. Simply, it is a thought process that promotes an engineer's holistic approach to problem solving, or "an approach to creative problem-solving which can be applied more broadly by people who are not necessarily designers" (p. 72-73)[6]. Among other things, elements of design thinking include:

- Empathy towards others
- Collaboration and an acceptance of diversity
- An openness to new perspectives
- Creativity
- Critical thinking[6]

These skills represent type of skill set than straightforward technical knowledge. Colleges and universities seek to graduate engineering students who can engage in the complex nature of combining both technical performance with design thinking skills to meet the needs of an ever-changing world. However, scholars still do not understand how design thinking academic experiences influence perceptions of competence and engineering identity.

Theoretical Framework

This study is grounded in role identity theory[7,8] and prior engineering identity development scholarship [5,9]. Role identity theory explores the multiple meanings that are attached to context and sociocultural roles. It states that an individual may have multiple identities which become more or less important depending on their contexts and, as a result, will align their behaviors with their roles in order to remain in the community[7,8]. As part of identifying as an engineer, students much negotiate the roles that they have both within and outside of the classroom. Engineering identity scholarship centers upon understanding how students come to envision themselves the type of individual who can engage with engineering [5,9]. Engineering identity is made up of three core areas: interest, recognition, performance/competence. Interest refers to the intrinsic desire to learn and be immersed in engineering whereas recognition refers to self- and outside recognition by others that a given individuals is an "engineering person." Performance/competence deals with the social performances of engineering practices as well as the knowledge and understanding of the content. Through performance and competence, individuals can envision themselves in the role of an engineer. Within this study, we draw upon role identity theory and engineering identity to understand how CES engineering students make meaning of their various roles and design thinking experiences and how understandings those influence their perceptions of what it means to identify as a successful engineering student.

Methods

A case study approach was used to undertake this study. Yin (2002) defines case as "a contemporary phenomenon within its real life context, especially when the boundaries between a phenomenon and context are not clear and the researcher has little control over the phenomenon and context" (p. 13). In this case, we sought to understand how electrical, computer, and software engineering students engage with design thinking and how that engagement shapes their

perceptions of what success looks like. As part of the NSF-RED grant, our team focused on the development of student engineering identity, how it was informed by design thinking, and how students described the process of engaging with design thinking pedagogy in their middle years courses. The design thinking intervention is a highly scaffolded, low-stakes introduction to design thinking. It utilizes design tools seen in other disciplines which have been redesigned specifically for use in engineering design contexts to promote user empathy, and encourage creative problem-solving and solutions. Table 1 provides a sample of the design thinking activities used in the course.

The researchers were not involved in development and implementation of the design thinking pedagogy intervention; instead, we were there to capture students' perceptions of it and how it informed the shaping of their identities as engineers and therefore had little control over the intervention or the students' response to it. To answer the research questions using this design, this study had established boundaries in order to create a "bounded system." We focused on the experience of students in specific courses (Circuits and Embedded Systems) that received the infusion of design thinking pedagogy. These courses are housed in the electrical and computer engineering department and students from computer engineering (software and computer engineering) and electrical engineering enrolled in these courses.

Also following the characteristics of case study design, we collected multiple forms of data for analysis. First, we conducted interviews with 21 students using a semi-structured interview protocol. The protocol included questions about students' interest in engineering, their performance in the course undergoing redesign, and their understanding of design thinking as presented in the course. Using announcements in class, flyers to advertise the study, and assistance from class instructors to post announcements on the course website, we recruited students who met the following criteria: (a) they were 18 years of age or older; (b) they were majoring in a CES major; and (c) were currently enrolled in one of two courses currently undergoing redesign: a second-year electrical engineering course called Circuits or a second-year computer engineering course called Embedded Systems. Interviews took place in a private place of the participant's choosing, typically the interviewer's office in another building on campus. Once informed consent was obtained, students completed a pre-interview survey to gather demographic information about them, and then interviews lasted on average 45-minutes to 1 hour. Students were asked about their interest in engineering, how they felt about their engineering experiences, and what design thinking meant to them. Second, we conducted approximately 50 observations of the lectures and labs attached to the Embedded Systems and Circuits courses. Using a protocol to guide the observations, we specifically looked for moments of positive or negative recognition, competence, and interest. We also looked for elements of design thinking that may have included students talking about their client's need for group projects.

The findings reveal that students engaged in the design thinking course described a disconnect between design thinking elements of the course and their perceptions of what it meant to be a successful electrical, computer, or software engineer. Although design thinking concepts focused on empathy-building and customer needs, it was often difficult for engineering students to see beyond the technical content of their course and conceptualize elements of design thinking as essential to their successful performance as engineers. This study bears significance to practitioners and researchers interested in (re)designing curriculum to meet the growing needs of

innovation for today's customer's. Implications for policy and practice will be discussed to enhance the way that engineering programs, curricula, and workforce training are created.

Results

The study sought to understand how ECS engineering students made sense of design thinking in an academic course setting and how design thinking in an academic course shaped perceptions of what it meant to identify as an ECS engineer. Table 2 provides a summary of the results, with greater explanation below.

Students Engage with Design Thinking to Improve Engineering Practices

Within our observations of the course, students primarily engaged in design thinking processes during the lab component of the course, rather than the lecture component of the course. At the beginning of the Fall 2017 semester when the DT content was introduced into an Embedded Systems course, students were introduced to this content in different ways. Some students were simultaneously enrolled in their Senior Design course, where students in that course received a 1-hour workshop on the specific elements of design thinking. During the Embedded Systems lecture meetings, and subsequently through homework, students' design thinking processes were often limited to applying technical competency in confined parameters of that week's particular skill-building exercise. The labs provided much more opportunity for students to engage with design thinking processes.

Within the lab portion of the course, students were put into teams, then asked to create robots that could solve various problems and carry out multiple functions. The development of students' final projects using the robots required them to fill out an empathy map as they developed the backstory of what students imagined their programming of a robot would simulate. For example, one group of students imagined their robot to simulate car technology that would sense children in the parking lot of a playground who the driver could not see, and the car technology could stop the car before it struck a child. Over the second half of the semester as students worked on the project, students were to continually think about how their programs contributed to society or to solving social problems, how they incorporated perspectives of potential clients into the design, and what creativity and critical thinking they brought to the project. Through these labs, students highlighted the importance of engineering design-thinking to both academic and industry related practices, particularly as it related to communicating ideas with others and exploring multiple ideas for solving problems.

One participant noted the importance of design thinking when approaching classroom projects:

> You can't do anything without design. Because you have to be able to design it, do it and display it in a way that everyone can see it as your view. I give credit to people that can do that. And that's the hard thing, to be able to do something like that so that everyone gets a picture. Even if you don't have the right mindset to it, you can pick up on what's going on and you can see everything that's going on. Design's a huge deal if you ask me. You can't do anything without it. Because if not everyone's on the same page, then it does no good. A good design can really bring it altogether. – Logan, Electrical, Man

As Logan notes, design thinking is seen as a way in which engineering students (and engineers) can thoroughly explore a project by communicating with others. In his engineering project, he strived to think like a designer because he knew that it was an important element not only to demonstrating his competence and ideas but also as a tool for bringing teams together.

Another student, Amelia, expanded on how engineering design thinking encouraged communication and the ability to work within a team-based setting:

> you really do need to work with people, so you need to learn how to communicate so also building your communication skills as well and learning to work with other people. – Amelia, Computer, Woman

For Amelia, engineering design thinking was not solely about the technical competence. Building upon the technical competence, design thinking encouraged students to communicate and work well with peers. It added another dimension to what it meant to be a successful engineer.

Students also believed that design thinking engineering practices lead to better problem-solving, especially in team-based settings. Priscila, a woman majoring in computer engineering, related that: "it's very important to learn design thinking and understand that people think differently, and not one solution is the right ... It's not always the only solution." Another student expounded on this idea, emphasizing the important contributions that design thinking can make:

> That's the first part of the design thinking is explore. Explore what problems need to be solved. Explore why they haven't been solved. Explore how you could solve them… people just don't think that way right off the bat. If they've got an idea, they wanna run with it. They take it as fast as they can. You have to say, no, slow down, let's think about all the options. Let's find real reasons to choose something, rather than this was my idea, so I really like it…we would go down the wrong path because [an idea] was cooler than it was better. – Corey, Electrical, Man

For this student, design thinking could lead to more accurately addressing the needs of end users and providing well-thought out context-based solutions. Although this process might take longer, it provided a more systematic way of evaluating ideas in order to select the most appropriate solution to the problem.

Students Struggle to Connect Design Thinking as Integral to Engineering Identity Formation

Throughout the observations, it was difficult for the observers to delineate exactly what were elements of design thinking and if students recognized them as such. For example, the observations notes mark numerous times when students encountered trouble debugging their code or making their robots work. To troubleshoot this, students turned to their lab manuals or to

the teaching assistants rather than looking for creative solutions to the problem. Even in designing their back stories for the final projects, one set of observation notes read:

> When I talked to students about their projects, they seemed like they were interested to play with the Roombas (the modified robots that they are programming as part of the project), but they didn't seem excited about the design thinking elements of it—especially in having to craft a back story that cultivates a sense of empathy about the problem they were addressing with their project. In short, it was as if the design thinking felt "tacked on" to the project—students were following certain steps because it was mandated by the class but they weren't excited or interested in it.
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> -Lab observation notes, October 24, 2017

Despite efforts to incorporate design thinking elements into final projects such as empathy or creativity, students did not recognize these components as essential to their classroom experience and training as future engineers.

When asked directly about their own exposure to design thinking and how that connects to their identity as an engineer, some students struggled to see these concepts as integral to their engineering identity formation. Students believed that engineers were individuals who had high levels of technical competence and engaged in creative, real-world problem-solving. Students discussed how they struggled to see design thinking as a means to identifying as an engineer because, in their experiences, design thinking had not been clearly connected to other engineering elements and creating creative real-world solutions. One student believed that the newly integrated design thinking elements were "distracting" to the current curriculum:

> The reason why I so strongly feel that the design thinking component is distracting, from the lab or the course, is because everything that helped me grow as an engineer was already in place and was what I was looking forward to putting my heart and soul into, and then we added something that didn't make me want to do it… That's a class-wide perspective. – Chad, Electrical, Man

For Chad, the original curriculum was sufficient for his engineering identity journey. His growth as an engineer was not improved by design thinking elements and even decreased his interest in engineering. Unlike other students who embrace design thinking elements, the social aspect of his engineering identity seems irrelevant to his training. Another student emphasized the disconnect between design thinking, real-world problem-solving, and his design thinking course:

> What actually would make me feel like an engineer is that when I would know that this is a real world problem…and if I succeed in doing that, I would feel that, "Yes, I'm an engineer right now. I feel like an engineer, where I actually solved real problem." But when I'm doing my labs in [the course], that's the only point when I could actually feel anything in the class… – Ajay, Computer, Man

Despite the efforts of the faculty to create authentic design thinking experiences, Ajay could barely feel the positive effects from the curriculum change. Although the labs provided some ability to feel like an engineer, the design thinking elements were uninspiring to him. Joseph, another student in the class, felt as though the course's design thinking implementation and lack of creative opportunities might be part of the issue. When asked how design thinking came up in his course, he replied:

> The way you think is going to influence how you are as an engineer…They tell us how to do certain things. If we wanted to, like they're having us design ... if he would have us design a circuit. He has circuits that, he gives us everything we need to do to be able to design a circuit. But in the end, most people probably end up coming up with about the same exact circuit, unless someone decided they wanted to be really far out – Joseph, Electrical, Man

For him, the design thinking elements of the course, and, in particular the lecture, did not inspire one to feel like a creative, problem-solving engineer. As a result, design thinking engineering is seen as more based in technical competence and prescriptive in nature.

Students also explained that "design" or "design thinking" were elements generally more associated with the work of the institution's College of Design, and, in particular, the Industrial Design Program, rather than elements in their own classroom. From our observations, even when students were working on "design projects" in lab, they were using a dramatically different design process than the one presented in lecture and the one the grant has attempted to incorporate into the curriculum. There was little to no human-centeredness, little ideation, or empathy, or thinking about the user.

When asked about design thinking, one student observed:

> I mean again I have a friend in the design college, I think he's talked a little bit about [design thinking, however,]…No. I wouldn't say so. Some of [my professor's] homework, actually on the homework that we have this week, it says "design a high pass active filter that has a corner frequency of 1000 Hz" and we have to plug in the equations, learn how to do that, and then design the circuit. But all of it's pretty basic stuff. He kind of gives us constraints. So I guess it is partially design. – Nicholas, Electrical, Man

For Nicholas, the ideas associated with design thinking were more easily connected with the college of design, which, at this institution, has a robust design thinking and creation curriculum, including professors who specialize in design thinking, courses in design thinking, and a first-year core design program. In part, this association also appears to come from the instructors themselves who are not differentiating "design" as part of the project development process and "design thinking" as an overarching approach to problem solving and thinking about the end goal. Therefore, students do not necessarily think of themselves as engaging in design thinking, or, in some cases even in more technically-based design projects.

One student, who was both in engineering but also completing an independent study in industrial design suggested that the connection between engineering courses and design thinking might need strengthening in order to gain student buy-in and promote learning connections:

> The new design thinking aspect of it, I think is interesting especially doing an independent study with [my professor]. It's in Industrial Design. So, I see a lot more value in the design thinking than I lot of my peers do. I think it definitely there's kinks to be worked out because it's the first year being introduced into the program, but I see a lot of value in it. It just needs to be ironed out, in my opinion. I think a lot of engineers are struggling with the design thinking now because they haven't been exposed to it earlier, but it makes a lot of sense for an engineer to understand kind of why they're doing the things that they're doing…if you want to a good engineer, you do have to understand this design thinking. So, a lot of students now, I think, they see it as a nuisance, but I think if it were introduced earlier in the program and more integrated into the program then it's something that would, in the long run, benefit the entire department.
>
> – Amanda, Electrical, Woman

For Amanda, design thinking was an important part of what it meant to be an engineer. However, as she noted, the implementation of design thinking elements could be improved, particularly as it related to how her peers viewed the integration of design thinking elements.

Discussion & Implications

Design thinking was implemented into specific sophomore and junior-level courses for electrical and computer engineering majors with the intention of better connecting students' personal identities with their work in the major and engineering profession. In many cases, students articulated the importance of design thinking to their professional formation. Students believed that design thinking was important to communication between team members, provided a clear process for exploring a variety of ideas, and lead to better problem-solving as engineers. Results also revealed that students engaged in the design thinking course described a disconnect between design thinking elements of the course and their perceptions of what it meant to be a successful electrical, computer, or software engineer. This study revealed that students' concept of what made them successful engineers was still tied to technical knowledge and the successful attainment of skills that they demonstrated in their engineering course labs. Although design thinking concepts focused on empathy-building and customer needs, it was often difficult for engineering students to see beyond the technical content of their course and conceptualize elements of design thinking as essential to their successful performance as engineers.

In terms of implications for future research, we suggest that future studies look at exemplary design thinking programs, particularly those which have been implemented for several years. This research could garner additional information about what practices and policies work over time and for the greatest number of students. In addition, future research might gain additional information from interviewing faculty and teaching assistants engaged in implementing design thinking curriculum. This research might be particularly helpful as we think about ways to

improve how we introduce design thinking to undergraduate engineering student audiences and train faculty to create their courses with design thinking processes in mind. This may be of particular interest to the scholarship of teaching and learning community (SoTL) who focus on improving engineering teaching practices. Finally, researchers may also want to concentrate efforts on exploring all elements of the engineering identity model, including what it means for students to acquire and maintain interest in ECS majors as well as how students gain a sense of recognition they are engineers.

In terms of implications for policy and practice, this study points to the need for strong implementation practices related to design thinking. Although most students recognized the importance of design thinking as part of their curriculum, some students struggled to see its connection to the engineering curriculum and to their development as an engineer. Accordingly, design thinking elements must be rolled-out in a cohesive manner and adequately integrated throughout the curriculum in order to get the best results. This study also demonstrates that design thinking must be expertly crafted to connect to real-world solutions, rather than just hypothetical or example problems. This might mean collaborating with industry partners to solve real-world problems with design thinking techniques or taking greater time to explain to students the real-world application of the design thinking activities. Finally, this study also points to the need to integrate and incentivize creativity in design thinking courses. Rather than merely allowing for creativity, students must see the value of utilizing design thinking to create creative real-world solutions that actually make them feel more like engineers.

Limitations

This study was conducted at a single research-intensive, engineering-intensive university in the Midwest. Utilizing only one institution limits the ability for these finding to be generalizable across all engineers or across all universities. Including more sites can allow researchers to explore patterns among geographic locations, engineering sub-disciplines and institutions with more or less emphasis in the STEM disciplines. Finally, this study, which is part of a larger study, explores data provided by students during one interview. We call for research designs that are more longitudinal to better assess how students' engineering identity develops over time.

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Appendices

Table 1. Sample of Design Thinking Activities

Design Thinking Activities
Departmental design thinking workshops
Design thinking lab modules (9 total)
Application story development
Jigsaw activity for datasheets
Written reflections on design thinking experiences
Industry visitors in lab
Use-oriented design considerations exercise
Technical/user design thinking process illustration
Modified empathy mapping activity
Sociotechnical debate
Final lab project: Creativity elements Writing own application story Team contract Code review

Table 2. Summary of Results

Theme 1: Students Engage with Design Thinking to Improve Engineering Practices
- Design thinking and building identity primarily takes place lab settings - Design thinking as a means for becoming communicative, team-oriented engineers - Design thinking as a means for becoming better problem-solving engineers
Theme 2: Students Struggle to Connect Design Thinking as Integral to Engineering Identity Formation
- Struggle to connect design thinking elements to technical tasks of course - Struggle to connect design thinking as integral to engineering identity; distracting from real engineering work - Design thinking encourages creativity, but when not required, students do not engage in creativity - Design thinking not a part of engineering identity – belongs in institution's College of Design - Connection between engineering and design thinking needs strengthening