ENGINEERING GENDERS:

A SPATIAL ANALYSIS OF ENGINEERING, GENDER, AND LEARNING

by

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Abstract

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Engineering Genders: A Spatial Analysis of Engineering, Gender, and Learning

Thesis directed by Associate Professor A. Susan Jurow

This three article dissertation is an investigation into the ontology of learning insofar as learning is a process of becoming. In each article I explore the general questions of who is learning, in what ways, and with what consequences. The context for this research is undergraduate engineering education with particular attention to the construction of gender in this context. The first article is an examination of the organization of freshman engineering design. The second article draws on Lefebvre's spatial triad as both a theory and method for studying learning. The third article is an interview study of LGBTQA students creating their futures as engineers.

Dedications

To Maggie and Hedy, you are my heart.

To Kale, my partner (that is his name, not the vegetable), thanks for doing the dishes.

To the Weidlers, because I will always know where I get my strength and my crazy.

Acknowledgments

I want to thank the students of GLE for welcoming me into the spaces of their lives. I will be forever grateful for sharing in their laughter and becoming. I hope that I have honored their voices and served them well, knowing I cannot possibly express all that I have learned from them.

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INTRODUCTION

In one of my early drafts of an article for this dissertation, I tried to condense everything I know and believe about learning into a single paragraph. I wrote:

> Learning is a process of becoming. As such, learning creates new ways of being in the world, enabling learners to both perform in new capacities as well as be recognized by themselves and others as having negotiated new identities. Learning, however, is not an abstract phenomenon; it is contextualized and located within social practices, practices imbued with cultural meanings and histories but that are also dynamic and changing.

Each one of these statements is a placeholder for a body of research that comes before it. I could pull out a single word and tell you why it is important to the study of learning: process, becoming, being, identity, practice, culture, change. However, without a context or theory behind each concept, they appear vapid; and yet, it is my hope that after reading this dissertation, the reader can come back to this paragraph and acknowledge that my primary focus for this dissertation is learning: learning from a situated perspective that that attends to both the change in individuals and practices.

The context of my research is undergraduate engineering education. I began my empirical investigation examining how students studying engineering are produced through gendered discourse. Gender is a salient theme in my research because much of our social world is made meaningful through the construct of gender, and gender is made consequential in most social practices. By analyzing discourse, including the rituals and routines of engineering education, as well as the spatial representations of engineering practice, I wanted to uncover both the constraints and possibilities for transforming learning environments to be more gender equitable. Engineering education presented a valuable context to study the gendered production of learning environments because it historically has been and continues to be a field disproportionately male despite sustained efforts to change.

Engineering was the practice that I studied. Although I studied multiple learners within the practice, I included a student group of lesbian, gay, bisexual, transgender, and queer individuals in my study both because they complicate our understanding of gender by rejecting heteronormative assumptions related to gender, and they were actively trying to change engineering practices to be more inclusive of multiple gender expressions and sexual identities as they negotiated their burgeoning identities as engineers. By including this group of students in my research, I was able to examine in what ways do disciplinary practices expect and prohibit particular types of participation and how do students create new ways of participation thereby transforming the discipline?

As I further describe below, each article in this dissertation represents a different facet of learning. I begin by examining organizing features of freshman engineering design classes giving a glimpse into the social practices constituting engineering education. In my second article, I consider how our theoretical and methodological approaches to studying learning can be bolstered by incorporating Lefebvre's spatial trialectic framework (1992). In my final article, I use the voices of the students I observed to show how learning involves imagining and thereby creating possible futures.

In the sections that follow, I give more background to the problem of the underrepresentation of women in engineering and how women in engineering have been studied from a situated learning perspective. I then articulate the social theory that informs this research followed by a brief discussion of my goals for this dissertation. I conclude with an overview of each article.

The Underrepresentation of Women & Situated Perspectives of Gender in Engineering

Despite decades of research, as well as programmatic efforts to change, underrepresentation of women in STEM disciplines persists (Hill, Corbett, & Rose, 2010; NCWIT, 2014). At the time this research was conducted, women represented 18% of undergraduate engineer degrees awarded; the most recent survey shows this number has risen to 19% (NSF, 2015). The problem of underrepresentation has been so persistent for so long numerous attempts have been made to synthesize all the research to date and possible solutions (e.g., Kanny, Sax, & Riggers-Piehl, 2014; Corbett & Hill, 2015). This has not prevented the call from industry, presidential commissions, and other organizations to increase participation of women in STEM fields (NRC, 2011; The White House 2009; NCWIT, 2015).

Researchers have long theorized about the culture of engineering (McIlwee & Robinson, 1992) and the subsequent framing of women in the field. Karen Tonso (1996a, 1996b, 2006) deserves particular attention regarding the way in which cultural norms have impacted women’s learning experiences in engineering. She used ethnographic methods and theories of situated learning to document how students learned what it means to be an engineer by being enculturated into the practices, meanings, beliefs and traditions of engineering. Her work, particularly on team formation (1996b) has been influential to engineering educators in the organization of undergraduate design classes.

How engineering is framed impacts the ways in which women are expected to participate in the field. There is a tendency to see engineering, and design in particular, as the "nuts and bolts" of a project (Faulkner, 2007). From this "technicist" view, engineering is made up of the tangible tools and representations needed to go into a project. This view includes disciplinary knowledge (e.g., math and physics) but ignores social processes of design. However, when you look at a quintessential engineering project, such as building a bridge, it is evident that social processes cannot be ignored, the technical challenges often represent a small fraction of the design process, and the technical and social are mutually constitutive (Suchman, 2000). The design and construction of a bridge is a networked process that involves a heterogeneous array of people, however, heterogeneous engineering encompasses more than simply "nuts and bolts and people" (Faulkner, 2007). Technicist views of engineering have greater consequences for women than men. Engineers, men and women, equally engage in both technical and social processes related to their everyday work. Faulkner (2007) demonstrated how work that is technical is often talked about as “hard” and “real” engineering while the social is often talked about as “soft” and “not-real” engineering. Furthermore, the technical aspects of engineering get coded as masculine, and the social gets coded as feminine. Faulkner (2009a) argues that “doing the job” of engineering entails “doing gender” in engineering. In her companion piece, Faulkner (2009b) argues that the expected gender performances in engineering are seen as *authentic* to men and *inauthentic* to women. Women are therefore subjected to an “invisibility paradox” in that they are highly visible as women, but invisible as engineers. As they try to navigate this paradox they experience the contradictory pressure to be “one of the guys” but not lose their femininity. To combat this tendency, she recommends drawing on concepts such as gender performativity (Butler, 2006) and post-structural feminism to begin to redefine and create multiplicities of gender in engineering.

My study built on prior research on learning to become an engineer from three perspectives. First, I built upon the work of Faulkner (2007) and Suchman (2000) to further the argument that a technicist view of engineering is an impoverished view of engineering, and in particular freshman engineering design. Second, I continued to investigate the pathways into and out of engineering (Stevens, et al., 2008), and how the pathways are organized according to gender. Finally, I examined the ways in which gender was discursively constructed in engineering and the possibilities for the creation of new gendered meanings (Stonyer, 2002). By attending to each, I examined the particular and contextual practices of both engineering and gender construction. This helped me see how the local processes of becoming a gendered engineer contributed to the re-production, and potential change, of gendering engineering practices, without losing sight of the broader social, institutional, and structural forces that aid in this reproduction.

Social Practice and Social Theory

Social practice theories of learning and development attempt to explain the changing nature of both the practice and the individual. It could be argued that engineering is a practice that does not change as women continue to be, and historically have been, underrepresented. I argue, however, that the practice is actively reproducing itself as masculine practice that constructs women in a particular way such that it results in their under-representation. Using social practice theory allows us to interrogate social and historical structures (Lave, 1988) as well as recognize how learning and becoming is a power infused process for both the individual and the practice (Bourdieu, 1977). To interrogate the power-laden construction of gender in engineering, I draw on critical theorists who look at the production, activity, and processes of human experience, and then make explicit connections to how their ideas can contribute to meaning making in engineering. I briefly describe the concepts of *normalization*, the processes by which actions appear to natural in a given context (Foucault, 1995), *gender performativity*, the socially agreed upon characteristics that express an individual's sex category (Butler, 1996), and the *social production of space*, the underpinning of all social relations, (Lefebvre, 1992). All of which informed this research.

A concept that is not made explicit in each article, yet greatly influenced how I understood engineering education, was Foucault's (1995) concept of *normalization.* Normalization is the process that makes behaviors and actions appear to be natural or normal. Establishing a norm creates criteria that can be measured and allows for people to be ranked on hierarchies of qualities, skills, and aptitudes. The concept of normalization is useful in researching engineering education as it highlights the importance of recognizing engineering as a discipline. A discipline is defined and bounded by what is and is not considered part of the discipline, that is, by its norms. Internalizing the norms of our environment regulates our behavior. My research investigated how disciplinary norms were created and represented and with what consequences, as well as how they could be contested, reestablished, and transformed.

Gender norms are powerful in disciplining how we act in the world. To understand gender norms I rely on Butler (1996). Butler differentiates biological sex (male, female) from gender (masculine, feminine), and that our knowledge of both is produced through discourse. Gender is a performance that constructs the social order of what is thought to be "normal." Butler argues that there is a tendency to see biological sex (male, female) as causing gender (masculine, feminine), which in turn causes sexual desire (homosexual, heterosexual). This view, however, is part of hegemonic structure of sexuality that forces categorization into oppositional binaries of male/female and masculine/feminine. I draw on Butler's ideas to reaffirm that both women and men can present as masculine and feminine but because engineering is "marked" as male, women are seen as not belonging regardless of their gender expression (Faulkner, 2009).

The final critical theorist informing this work is Lefebvre and his construct of the spatial trialectic (1992). In brief, space, along with time, is a constitutive underpinning for all human action and social relations. Space produces the ways in which people are able to act in the world, and the ways in which people act in the world produces space. I use Lefebvre's theory of space similar to dialectical materialism in that I employ the spatial trialectic as both a theory and method in understanding learning in the disciplinary practice of engineering. The trialectic method is a useful tool in both uncovering how engineering as a discipline is defined through organizational practices and how these organizational practices can be transformed.

Goals of this Dissertation

This research is interpretive insofar as it seeks to uncover "meaning-in-action" (Erickson, 1986). This suggests that by examining the immediate and local meanings of actions, we can come to understand the broader social influences and organizing features that contribute to social action. This research is also critical in that it recognizes that people's actions and choices are constrained by various forms of social, cultural, and political order. By taking a perspective that is both interpretive and critical, I hope to uncover the reflexivity between meaning construction and social order, with particular attention to how we can create a more just and equitable world.

The primary goal of this dissertation is to use the context of engineering and the examination of gender in particular to think about the ways in which disciplinary practices are organized and the consequences this has on who is enabled to become recognized as a particular kind of person within the discipline, in other words, how is learning organized within a discipline such that this organization supports certain identities but not others. Although one audience for this work is engineering educators seeking to reorganize practices to be more inclusive, the work is intended for all audiences who think deeply about how to design for learning.

Article Summaries

Article 1: A Heterogeneous Perspective on First-Year Engineering Design Education

As mentioned above engineering is often seen from a technicist perspective (Faulkner, 2007) overlooking how the social is not just a part of design, but how design is a co-constitutive process of social and technological elements, or that it is a *heterogeneous* process (Suchman, 2000). In this article, we examine how undergraduate engineering education represents a sociotechnical system and that taking a heterogeneous perspective on design instruction shows the many ways in which students must navigate people, materials, and theory in such a way that their learning experience can only be understood from a framework that captures this complexity. Using an interpretative case study approach, we examined two sections of first-year engineering design. Our findings suggest that (1) A heterogeneous perspective articulates consequences of design instruction that favor certain aspects of design. (2) The introduction of actors (i.e. space, people, resources, tools) in the course plays an important role in how students learn design. (3) Boundary objects (including prototypes or written documentation) created by the teams in the courses act as an organizing tool that mediates sociotechnical activities in which students engage. We conclude by arguing that because design instruction, like the design process, represents a sociotechnical system, engineering educators should facilitate student opportunities to purposively engage with the systems of design and be mindful of the organization of the class to best integrate the heterogeneous elements of design for students in their courses.

Article 2: An Argument for a Spatial Analysis of Learning

Drawing on Lefebvre's (1992) spatial trialectic as both a theory and a method, I present spatial analyses of two students becoming engineers. I argue that this spatial analysis provides a new lens for understanding the phenomena of learning to become an engineer, contributing to both general theories of learning as well as methodological approaches to studying learning. In order to frame these student case studies, I discuss the historical foundations of socio-cultural approaches to learning and develop a foundation for researching and interpreting learning from a spatial perspective. By comparing two cases, one of spatial coherence, and one of spatial disjunction, I demonstrate how a spatial approach to learning enables the concepts of *disciplinary practice, equity,* and *transformation* to be held together during our research of and organization for learning.

Article 3: Transformation and Stasis: LGBTQA Students' Prefigurative World of Engineering

The underrepresentation of women in Science, Technology, Engineering, and Math disciplines continues to be researched and programs are continually developed to address the dearth of women in STEM. Educators have called for this phenomenon to be studied from an intersectional approach, which includes sexual identity. This article examines how a group of students interpret their ability to transform the field of engineering to be more inclusive. Drawing on interviews from eight LGBTQA undergraduate students in the process of becoming engineers, I show how these students draw on engineering concepts to both reimagine and reorganize engineering to be a more inclusive environment for sexual orientation. Although challenges persist for women, I argue these students create new possibilities for equity in engineering by enacting prefigurative worlds.

CHAPTER TWO

A Heterogeneous Perspective on First-Year Engineering Design Education

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Abstract

Heterogeneous engineering is the view that engineering design is a complex system of mutually constitutive social and technical relations. This study examines the *heterogeneous* nature of design through an interpretative comparative case study examining two sections of a first-year engineering design class. The study was guided by the following research question: “What can we learn from comparing differently organized sections of a first-year engineering design course?” Based on an interpretative case study approach we present three main findings: (1) a heterogeneous perspective articulates consequences of design instruction that favor certain aspects of design, (2) the introduction of actors (i.e. space, people, resources, tools) in the course plays an important role in how students learn design, (3) boundary objects (including prototypes or written documentation) created by the teams in the courses act as an organizing tool that mediates sociotechnical activities in which students engage.

Keywords: first-year engineering design, heterogeneous engineering, interpretive case study

Introduction

Engineering educators continually explore research-based ways to improve upon instruction of design courses in relation to student success and retention with particular attention to cornerstone or first-year design (Sheppard et al., 2009; Litzinger et al., 2011; King, 2012). Design courses are often organized to emphasize either the technical and practical skills needed to support design or the cognitive and theoretical principles of design. While we recognize the importance of both theory and practice in engineering design, we argue that reinforcing this distinction between the two obscures the ways in which engineering is a *heterogeneous* process. A heterogeneous perspective views design as a process that inextricably combines technical and social relations into a *sociotechnical* system in which neither aspect, the technical nor social, is adequately understood without the other (Latour, 1987). Such a perspective acknowledges that engineering design involves more than people and materials; rather, social relations and meanings are integral and inseparable to the process, and neither people nor materials are constituted apart from this process (Suchman, 2000; Trevelyan, 2007). Similarly, a heterogeneous perspective on design instruction shows how students are produced as students through activity in the sociotechnical systems of instruction: namely, in any given design project students interact with people, materials, and theory in such a way that their learning experience can only be understood from a framework that captures this complexity. By bringing a heterogeneous perspective to design instruction, our research uncovers new ways of thinking about organizing and planning for design courses.

As part of a larger ethnographic project investigating design in both engineering education and workplaces (Lauff et al., 2014), we studied two separate sections of a first-year engineering design course, ENGR1000, at a Research I, public university. These two courses were identical on paper; they counted as the first-year engineering design course required for all engineering undergraduate majors. The course description states “first-year engineering students work to solve real engineering design problems in interdisciplinary teams.” One section was a hands-on, technical skills-based class taught in a facility constructed to reinforce contemporary engineering pedagogy we call the Hoover Center[1], or HC for short. The entire HC building was designed to support engineering education by enabling learning by doing and providing all of the material and people resources to support design within the same building. The HC’s approach to design courses is through project-based learning. This course is referred to in this paper as the “technical skills-driven section.” The second section, focused on cognitive awareness of design theory. It was taught in a student residence hall through an International Living and Learning Program (ILLP), which is a part of the larger campus-wide Residential Academic Programs. Class sessions were held in a multi-purpose room. This course focused primarily on design thinking methodology, which is a specific way to think about and approach design, and used this to guide students’ understanding of design. This course is referred to in this paper as the “cognitive theory-driven section.”

Given the different spatial and theoretical organizations of the sections, we expected differing outcomes for the student teams based on their section. We sought to understand the importance in organizing the same course two ways: the first being located in a building and classroom intentionally designed to support project-based learning (technical skills-driven section), and the second located in a conference-style

[1] Hoover Center (HC) is a pseudonym. All names and locations are given pseudonyms throughout the

meeting room in which design-thinking was privileged (cognitive theory-driven section). The different sections, however, still met the criteria for an introductory first year-design course. Therefore, we sought a single theoretical perspective with explanatory force to capture the myriad of experiences, people, and tools that design students encounter while learning and enacting the design process through their design courses. Heterogeneous engineering provides a theoretical framework for understanding the multi-faceted experiences of engineering students. The question guiding our research was, *"What can we learn from comparing differently organized sections of a first-year engineering design course?"*

This paper is organized as follows. First, we explicate the concept of heterogeneous engineering and how it contributes to our understanding of learning engineering. Next, we provide a brief history of first-year projects in engineering education curriculum exploring ideas around integration of practice and theory in engineering design courses. Namely, we consider the use of project-based learning as well as the incorporation of the design thinking philosophy into the curriculum, as both of these are pedagogical approaches for the design sections observed. We argue that research to date overlooks some of the important experiences students participate in while engaging in design. In our discussion of the data, we show how students became connected, or not, to people and resources as they develop engineering skills. We believe that these connections deserve further consideration and study in order to inform pedagogical practices and the organization of instruction.

Heterogeneous Engineering and Learning to be an Engineer

Design is often considered to be the defining characteristic of engineering, and, therefore, engineering educators should promote design theory and skills to prepare future engineers (Dym, et al., 2005). However, many researchers have pointed out that how design is accomplished professionally is not often aligned with the teaching of undergraduate design (Bucciarelli, 1994; Trevelyan, 2010). This is due in part to an overemphasis on the technical elements of a design project while minimizing the social processes of design. *Technicist* views of engineering focus on the tangible tools and representations of projects often referred to as the "nuts and bolts" (Faulkner, 2007). This perspective shows how engineering draws on other disciplines including math and physics, and applies these disciplines to building and creating new tools and structures. A technicist view promotes an "ideology of engineering" that reduces engineering to the application of technical principles and processes in the service of solving technical problems while overlooking the ways in which social relations impact the technical processes (Williams, 2002). Engineering, however, is not simply "nuts and bolts and people" (Faulkner, 2007). When Suchman (2000) examined a quintessential engineering project, such as building a bridge, she found that social processes are not merely an important aspect of the design separable from the technical; rather, the design of the bridge represents the mutual constitution of material and social relations through the production of a stable artifact.

In her two-year ethnographic study, Suchman (2000) documented how bridge building required the organization of both human and non-human elements, and is thus what Law (1987) would label an example of heterogeneous engineering. Suchman demonstrated how discursive practices and physical materials must be assembled together in the construction of the new artifact. Building a public bridge not only requires the technological knowledge of bridge building, it requires an understanding of the bridge in relation to the larger road or highway system, its relation to the people affected by the bridge such as motorists, cyclists, and neighbors, and its relation to the environment and other non-human elements that are consequential to its coming to be; consequential insofar as these relations and not others are part of the networked process of designing the bridge. An account of the material stability of the bridge is inseparable from the understanding of the network of social practices related to the bridge including its design, construction, maintenance, and use. The construction of a bridge, because it is located within larger social practices, is a contingent process influenced by its particular historically and culturally constituted setting. The social aspects of design are not merely a constraint, but, rather, are co-constitutive to the design itself (Law, 1987).

Suchman (2000) attended to the ways in which engineers engaged in sense-making, persuasion, and accountability as they managed relationships with all of the actors in the project. In the end, the physical construction of the bridge was outsourced and represented a small fraction of the overall project of coordinating its inception. Building a bridge is a *sociotechnical* (Latour, 1987) project in that its social and technical aspects are inseparable. To ignore this, and adopt a technicist view of engineering, would be an incomplete view of an engineering project as well as an incomplete view of the work engineers do developing social relations in the construction of a bridge. Furthermore, the social elements of design should not serve as an explanatory afterthought since they are embedded in design practices (Law, 1987).

Just as focusing on the material construction is an impoverished view of how a bridge gets built, we argue that focusing only on classroom interaction, such as how students engage with the content and perform tasks, is an impoverished view of how students learn design. Students, by learning engineering design, are being produced via the mutually constitutive processes of social and technical organization. As such, a heterogeneous engineering perspective of instruction makes visible tensions and conflicts to the organization for learning, some of which are brought into alignment with the instructor and/or administrative goals for the course, while others are transformed or ignored.

Our conceptual approach to learning is a situated perspective in which learning is a function of the activity, context and culture in which it occurs (Lave & Wenger, 1991). Learning is a fundamentally social phenomenon and is about becoming a different person in relation to the possible identities one can develop through engaging in particular practices. The possible identities are constructed in the community in which they are defined: often “pulling-in” or “pushing-out” individuals from the practice (Stevens et al., 2008). As students learn the technical and theoretical elements of design, they also interact with people, places, and tools. In other words, they participate in sociotechnical systems: some intentional by engineering educators and some not. By following first-year design projects through their duration, we were able to document different facets of the sociotechnical system that educators may be unaware of but that have significant implications for students’ experiences.

First-year Engineering Design: A Brief History of Practice and Theory

Engineering courses specific to first-year students have varied over time in the United States. Sheppard and Jennison (1997a) documented how engineering curriculum has changed over the last sixty years ebbing and flowing between hands-on, practical courses to scientific, theory-driven courses, as well as how instruction has differed (Sheppard et al., 1997b). The change in engineering curriculum is attributable to external factors including national concerns, industry demands, and educational theory. The Grinter Report (1955) is an early example in which recommendations for more basic sciences such as physics, chemistry, and math were emphasized after World War II in engineering curricula. Hands-on courses in design were de-emphasized then, but gained traction again in the late 1960s when engineering educators reacted to the lack of design skills and understanding among their students. After this resurgence, they were again pushed aside in the 1980s to provide students with more theory in technology, in particular computer-related technology.

In the 1990s several factors converged to produce what remains largely the current state of first-year design courses in U.S. university-based engineering education. Research began to connect attrition rates to freshman curriculum, often showing in the first year that students “de-select” engineering majors, and there continues to be research to affirm the connection between project-based first-year design courses and lower rates of attrition (Picket-May & Avery, 2001; Knight, Carlson, & Sullivan, 2007). Pressure from industry, recommendations from the National Science Foundation Engineering Education coalitions and ABET, the Accreditation Board for Engineering and Technology, as well as the rise of constructivist learning theory among scholars in engineering education all encouraged a renewed interest in first-year design courses (Sheppard & Jennison, 1997a). Additionally, there has been a push for making design the "backbone" of the engineering curriculum by integrating design courses throughout students' entire four years (Dym, 1999). This push to incorporate design courses has added to the upsurge of freshmen design courses being established worldwide (Dally & Zhang, 1993; Sheppard et al., 1997b; Hirsch et al., 1998; Dym, 2004).

Instruction of first-year design courses has varied with common methods such as the use of full-scale projects, small-scale projects, case-study analysis and reverse engineering, as well as integrating projects with community service (Bazylak & Wild, 2007). The typical first-year design course includes lecture-style presentation of the top-down, step-wise refinement design methodology (Gander, 1994). Alongside the theory, there is usually a project-aspect to reaffirm the presentation of the methodology. Design projects are formulated in many different ways from industry or department sponsored, professor generated, to student developed. In addition to theory and practice, there is also an emphasis on aspects like design tools, design communication (sketching, 3D modeling, presentations, and writing), project management, and teamwork (Galle, 2002; Seidel, 2004).

The pedagogical approaches to teaching first-year design also vary. Over the years engineering educators have used a variety of learning theories to inform pedagogical practice, including active and cooperative learning, learning communities and service learning (Smith et al., 2005). Currently, the most popular approach to design courses is project-based learning (PBL) (Dym et al., 2005). PBL "is the learning that results from the process of working toward the understanding or resolution of a problem"

(Barrows & Tamblyn, 1980). In PBL, learning is student-centered and self-directed as students work in small groups with teachers as guides while a given problem organizes and provides the stimulus for learning (Barrows, 1996).

More recently, the philosophy of design thinking has been integrated into design courses (Oxman, 2004; Carelton & Leifer, 2009). Design thinking can be described as a "discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible" (Brown, 2008). This growing interest in design thinking has caused engineering educators to reorganize the way they teach their classes, with an added focus on user-centered design through empathy and a quick turn-around on prototyping iterations through a "fail often and early to succeed sooner" mindset (Kelley, 2007). When design thinking organizes teaching, students are expected to gain different skills, such as tolerating ambiguity and uncertainty, maintaining sight of the big picture, decision making, as well as the ability to think and communicate in several languages of design (Dym et al., 2005).

Often design courses are organized to have an equal balance between theory and practice. Brereton (1999) explored the benefits students gain from continuously shifting between theory and practice as she studied the dialogue with which students engage when linking engineering concepts with the physical tools or hardware of design. She demonstrated that the fundamentals of engineering are taken up and best understood when students negotiate the meaning of concepts in relation to the hardware used in their design. Likewise, Dym et al. (2005) urged design coaches to help manage the contextualization of design theory and practice. Performing and practicing design activities enables students to integrate thinking skills and design skills together (Leifer, 1987). In addition to design classes being a combination of theory and practice, engineering education researchers have described what a design project "should be" including its level of challenge, ability to be completed within the given timeframe, level of interest and research available on the topic among others (Debelak & Roth, 1982; Jakubowski & Sechler, 1994; Philips & Gilkeson, 1991, Litzinger et al. 2011).

As the research on first-year design suggests, engineering educators have engaged with both theory and practice to varying degrees over time. Consistently, however, design theory and practice have remained separate concepts to employ in engineering instruction resulting in the further isolation of physical processes from social processes. A heterogeneous engineering perspective on engineering design instruction shows how the social and physical elements of design are inextricable, a perspective not yet theorized in engineering education.

Research Design

The case study analysis presented below is based on a sub-set of data collected from a larger ethnographic project investigating the design practices of engineering students and professional engineers called Cognitive Ethnographies of Engineering Design (CEED). The primary purpose of CEED was to understand how the design process is organized, how professional design practices relate nominally to university design curricula, and how any continuities and discontinuities between work and school might inform efforts to design engineering curricula. Our case studies are developed from data collected during the educational, rather than the professional, portion of this study. The larger project, however, informed many of the decisions we made that we report on here. In this section we include a description of why a case study approach is the preferred method for answering *how* questions (Yin, 2009), the context of our study, a description of data collection, and methods used for the analysis.

Interpretive Case Study

Qualitative, interpretivist research is increasingly prevalent in engineering education research (Baillie & Douglas, 2014). Ethnographic methods are used in engineering education research related to design (Atman, Eris, McDonnell, Cardella, & Borgford-Parnell, 2014), particularly in the study of how students engage in the study of design (Goncher & Johri, 2015; Downey & Lucena, 2003), as well as how instructors enact curriculum to support the learning of design (Daly, Mosyjowski, & Seifert, 2014). Interpretive research investigates the local meaning of action in order to draw a comparison to broader phenomena (Erickson, 1986). Examining the particularities of two design courses increases our understanding of undergraduate engineering design not by generalizing from each but, rather, by articulating how each is unique.

We chose a case study approach where our unit of analysis was the design course. The design course consists of the interaction between the instructor, teaching assistants, students, resources and tools for design, and the curriculum. The rich description of a case study becomes a measure from which we can gauge our understanding of undergraduate design practices (Wolcott, 1990). It provides a way of both seeing and not-seeing design, thereby being instrumental in both examining and expanding our theoretical understanding of design (Stake, 1994). To establish credibility and trustworthiness in our study, we provided thick descriptions of our research setting, used multiple sources of data, triangulated our data, and performed member checks (Lincoln &

Guba, 1985). We studied the design courses using multiple forms of evidence including video observations, student work, interviews with the instructors, and course artifacts, further supporting the trustworthiness of the study (Miles & Huberman, 1994; Yin, 1994; Stake, 1995). The following sections describe the research context by detailing the setting, the design course, and study's participants.

Research Setting and Participants

The University and Engineering Program

The study examines two sections of the same freshman design project course, ENGR1000, at a Research I institution located in the mountain west. The university from which these project data are derived is a nationally recognized, award-winning engineering education provider and has a program dedicated to the teaching and learning of engineering: the Hoover Center for Engineering Teaching and Learning. The HC organizes and oversees all sections of ENGR1000 to ensure that each section is meeting the college of engineering objectives. As part of the organizational structure of the first-year engineering design courses, instructors of ENGR1000 meet weekly with the director of the HC to discuss the implementation of evidence-based practices in the classroom. For example, the practice of personality testing is recommended to inform classroom strategies such as team formation. The HC has synthesized best practices of engineering design education as defined by its directors and reflecting the ideals of the National Academy of Engineering into an introductory textbook for ENGR1000 instructors to use. The university ranks higher than the national average for both recruitment and retention of engineering undergraduates.

ENGR1000

ENGR1000 is a 15 week long, freshman-level introduction to design course with a project-based approach. Instructors provide the students with an open-ended question, problem, or challenge, and students respond by engaging in a hands-on design experience. Starting with the specification of design objectives and constraints, students are led through the development, documentation, and analysis of design ideas, and finish by building and testing a solution. Instructors for ENGR1000 vary; they include tenured professors, lecturers, and graduate students. Although the HC recommends best practices for course design, instructors are free to organize their courses around their preference.

Participants

The participants in our study include the instructors, teaching assistants, and students of both sections of ENGR1000, as well as support staff for all ENGR1000 sections. The technical skills-driven section had one instructor, two teaching assistants, and thirty students. The cognitive theory-driven section had one instructor, one teaching assistant, and forty-five students. In each section, one design team was followed for the duration of the design process. In the first section, the team was chosen randomly; in the second section, the team was chosen because their project aligned with our broader research in the CEED project. A description of each team follows in the sites of observation section.

Data Collection

We engaged in participant observation of both ENGR1000 sections for the duration of the semester. Both sections met for approximately five hours a week. We drew from qualitative research techniques for doing fieldwork (Czarniawska, 2007). These techniques include both direct and indirect observational methods to capture elements of participants' activities surrounding their design project (Lauff et al., 2014). During our observations we video recorded class time as well as wrote fieldnotes. When students travelled outside of the classroom, for example to a machine shop, we followed them and would audio record conversations. We also audio recorded and wrote fieldnotes for five weekly instructor meetings over one semester, informally interviewed the instructors during class time, as well as interviewed both the teaching assistant for the cognitive-theory driven course and the director of the HC. Additionally, we collected course documents such as syllabi and handouts, grading and scoring rubrics, as well as student end of the semester course evaluations.

Data Analysis

The project team met weekly to engage in constant comparative analysis, negative case analysis, and theoretical sampling of the design activities we examined (Glaser & Strauss, 1967; Strauss & Corbin, 1998). We discussed emergent themes in the data developed through open coding. Examples of these codes included people, tools, and spaces. Drawing inductively from heterogeneous engineering presented by Suchman (2000) we engaged in axial coding developing connections between our initial codes and began to articulate ‘‘when, where, why, who, how, and with what consequences’’ around each category (Strauss & Corbin, 1998, p. 125). Our analysis shifted to focus on explanation building (Yin, 2009) and articulating what are the salient elements of design. After our data was collected we employed within-case and cross-case analysis (Miles & Huberman, 1994). Within each case we looked for significant instances related to design including the space/location of design, and the development of relationships during design. These were then compared across the cases.

To ensure credibility and trustworthiness we include a thick description of the two ENGR1000 sections below as sites of observation (Lincoln & Guba, 1985). These descriptions along with our analysis were shared with the instructors of the course to increase the credibility of our research (Miles & Huberman, 1994).

Limitations

With all interpretive research there is a risk that a key perspective or insight was excluded which the inclusion of would significantly alter the interpretation of events. Similarly, there is risk that the researcher is overly biased in how events are detailed. These risks were minimized by, first, having a multi-disciplinary team of researchers including both engineering and education specialists; and second, we shared our interpretation of events with multiple participants and solicited their feedback.

Sites of Observation

The first-year engineering design observations took place in two different locations; one being the technical skills-driven section in the HC, a purposefully designed teaching and learning space, and the other being a cognitive theory-driven section in the ILLP held in a multipurpose room in a residential academic program. The HC program prides itself on drawing on research-based practices of engineering education, while also continuing to innovate classroom practices to motivate and prepare future engineers. The established and accepted methods of engineering education as well as new approaches to teaching are reflected in the different sections we observed. The technical skills-driven section of ENGR1000 observed was considered by many in the college of engineering to be a standard section because it took place in the HC building and within its oversight, while the cognitive theory-driven section was seen as experimental because it was removed physically from the HC building and was allowed to be structured and organized independently. The cognitive theory-driven section was part of the ILLP, a residential academic program where students live, as well as attend classes, in a shared dormitory in an effort to engage students more closely to their interests. For example, the ILLP section we observed was organized around the theme of global engineering as such this ENGR1000 section focused on design for international communities.

Next, we further describe each section below. Within each section, we provide descriptions of the observed classes, the students' design projects, and details of the classrooms and design workspace used by students. These details are meant to provide an account of the richness of students' learning experience.

Technical Skills-Driven Section: The Playhouse & LED Matrix in the HC

The technical skills-driven section of ENGR1000 was taught by Camilla[2], a senior instructor rostered in the civil engineering department. Camilla's syllabus stated, "the most important learning objective is to understand and apply the design process. That is,

[2] We use first names for instructors for ease of reading, and all names are pseudonyms.

design, build, evaluate, and repeat until the desired results are obtained." Over the course of the semester, workshops and lessons were organized around features of the design process. The first design activity was a short, four-week mini-project creating a bubble container that would not spill. This first project aimed to introduce students to the design process and get them comfortable working in teams. After this short project, the students begin the main ten-week project, the design of a playhouse, in which they are expected to define, budget, iterate, and construct a final product to present at the College Design Exposition. The final project counted for 50% of the grade and attendance and homework related to lectures and workshops counted for 35% of the grade. Students were expected to attend multiple workshops focused on skill-building including laser cutting, manufacturing, using power tools, working with SolidWorks (3D CAD modeling program), circuits, and Arduino among others. In addition to workshops, Camilla arranged for multiple guest speakers to attend class. They included the client, a machine shop supervisor who provided feedback during a design review, the electronics shop manager, engineering education specialists who discussed team dynamics and social styles, and various experts on building construction including a structural engineer, an expert in lighting, and a lecturer on aesthetics.

Camilla's class was taught in an intentionally organized classroom dedicated to the teaching of first-year design located in the HC, an entire building created and staffed to support engineering students. The HC staff supports different services such as the electronics shop and laser cutter, and aids in instruction of HC sections by giving lectures and presentations throughout the semester. Camilla's syllabus listed the HC resources that could be helpful in the course. These resources are listed by *what* they are, *who* can help, and *where* it is located. These resources include:

(1) machine shop that contains general manufacturing tools,

(2) proto-shack that contains laser cutters, 3D printers, and prototyping materials,

(3) electronics center that contains components to build breadboards and printed circuit boards (PCBs), and

(4) material check-out center that allows students to borrow a variety of tools, materials, and test fixtures for their projects.

Each of these locations has a main contact person who is introduced to the class through a workshop or tour. The syllabus listed the contact person's name, email address, phone number, and office location. The majority of students become quickly integrated into the HC space through these networks of people, which is a stated goal of the HC. They want students to feel "part of engineering," as well as have access to many people as first-year students.

The HC includes collaborative workspaces, reservable meeting rooms, computer stations, and various building areas where students can access materials and tools for their design projects. The building is designed to be a living, learning laboratory. Students and visitors walking through the building are met with displays and activities to introduce engineering concepts such as conduction, perpetual motion, or basic principles of dynamics. The walls are adorned with pictures and descriptions of engineering projects. Part of one of the building's walls has been left exposed with an explanation of how engineering principles were used in the construction of the building. All of these elements were intentionally created, which is an overarching theme to the HC's approach to learning. Every detail is designed with a purpose, right down to the physical layout of the building; the building is thought to be an extension of the students' classroom.

The classrooms specifically designated for the ENGR1000 are on the upper level of the HC. These two side-by-side classrooms are entitled "ENGR1000 Room A" and "ENGR1000 Room B," and are mirror images of each other in their layout. Each room is divided in half. One half has six oval tables on carpet, oriented towards a white board and projection screen. This is where students engage in discussion and lecture. The other half has six tall rectangular tables on linoleum tile floors. This is where students work on projects and can get messy. Along one wall are lockers, which contain toolkits for the students. Each team gets their own locker and toolbox, which includes basic tools such as screwdrivers, wrenches, and pliers. These lockers are intended to also hold any small portions of the groups' projects. If the team needs more room for their project storage, then additional space in the HC is provided for them. On the wall opposite the whiteboard are computer stations. There are enough computer stations for each team to use during the class, and engineering software, like SolidWorks, is available on them. Above the computers are rows of engineering reference books that include topics such as materials, chemistry, mechanics, and structures. The classroom is organized to meet the needs of classroom instruction and designing and constructing a project.

Everything in the classroom is organized for the purposes of running engineering design courses. This becomes clear when examining the space of the classroom: where the tile floor versus carpet is placed, the height of the sturdy worktables, the computers and reference books in the back, and even the tools in the toolboxes. The HC staff made purposeful decisions on how these classrooms should be organized. In addition to the physical space, the HC courses are expected to use a textbook written by members of the HC explicitly for first-year engineering design projects. The HC believes that introductory engineering projects courses should enable students to experience the full cycle of engineering which "begins with specification of design objectives and constraints, continues through development, documentation and analysis of design ideas, and ends with the process of building and testing the solution." The director of the HC described the primary goal of the first-year design course in his interview, "It's a team-based, hands-on design and build class. That's really the focus of the class. Everything is done in teams and the focus is on designing and building stuff. Probably the most important learning objective is for the students to really understand the iterative design process and that design isn't getting everything perfect on paper and then going and building it because it's not going to come out the way it was on paper because it doesn't happen that way." According to studies published by HC researchers, the intentional design and organization of ENGR1000 help make a difference in retention rates for engineering students, and in particular women and minorities because of the practices used to target these groups[3].

The HC director described the importance of a small classroom environment. "Each section is around 30 students. It is very intentionally kept small. That size is about right for the sort of interaction that we want." Not only are HC classrooms designed for these numbers of students, but also many of the classroom strategies are administered with this constraint of enrollments in mind. For example, the HC purposefully keeps the classroom support to student ratio low by providing instructors with two teaching

[3] References are omitted for confidentiality of the research location and participants.

assistants (TAs), who are generally engineering upperclassmen or graduate students. These instructors and TAs come from a variety of engineering specialties across the College of Engineering. The enrollment cap supports practices such as team formation. Teams are formed using a social styles assessment administered to students during the first two weeks of class; the assessment is intended to be a predictor of how students will approach various tasks and interactions. The HC provides recommendations on team formation that most instructors, including Camilla, follow. For example, the HC recommends that women be paired on teams with ideally only two women per team, and that social styles like those classified as “amiables” be distributed amongst the teams evenly (Merrill & Reid, 1999).

The semester culminates with the College Design Exposition in the HC. This is a mandatory part of the class, and factors into a significant portion of the students’ grades. On this day, the teams are expected to have a formal poster that is professionally printed, a short pitch prepared for the judges, and a working prototype. Prior to the Design Exposition, the class has multiple in-class design reviews on all of these aspects. At the Exposition, a panel of judges coordinated by the HC evaluates each team across all sections of ENGR1000 with an identical rubric as well as present their final design to the public to compete in the people’s choice award.

An account of students’ experiences in a section of ENGR1000 located in the HC would be incomplete without an understanding of the intentionality, coordination, and organization of both the HC building and staff. Although all sections in the HC have the same textbook, same location, and same underlying organizing features, each section remains unique in its focus on a design project. Each HC section has a unifying theme, generally of interest to the instructor teaching the course, such as environmental or biomedical-related. Additionally, there are also instructors who choose to work with "real" as opposed to hypothetical clients. For example, many instructors partner with local organizations to develop assistive devices for disabled community members, as was the case with the Camilla's section.

Camilla had previously taught ENGR1000 and felt students appreciated not only having a real client but also benefited from designing something of need for others. She had developed a relationship with a local family with two sons, one wheel chair bound with a severe motor disability and the other able-bodied. On the family's suggestion, Camilla decided to organize her class around a project building an interactive playhouse for the family that would ultimately reside in their basement. Of the six teams in the class, three teams were tasked with designing the playhouse structure, including building the walls and making it aesthetically pleasing. The other three teams developed interactive sensory devices to be integrated into the playhouse structure. The class, then, had to work together as a coherent unit to make sure all aspects came together in the final design, a unique approach for HC classes.

We observed one team developing two sensory devices. The team consisted of five members: Joshua, Cody, Nick, Katherine, and Maria. After brainstorming ideas, the team decided to develop two different LED light displays. One of the structure teams was building a platform that served above as a loft and slide for the able-bodied child, and below as a cave into which the disabled child could easily roll. The first sensory device was a motion activated light strip that would light up the cave. The second sensory device was what became referred to as the LED-matrix. The LED matrix was a three-foot by three-foot plastic-encased LED display that showed different patterns and colors when activated by a large button easily pushed by a child. It was to be hung on the ceiling of the cave. The team divided into sub-groups to work on each device. Joshua and Cody worked on the light strip, while Nick, Katherine, and Maria worked on the LED-matrix. We followed the latter subgroup more in-depth.

Nick generated the idea of the LED-matrix; he told us in an interview the idea came the first day of class. He had prior experience with electronics and was particularly interested in mechatronics, a multidisciplinary field of engineering that includes a combination of mechanical, electrical, controls, and software. He found a prototype of the design online: a 10-by-10 array of LEDs programmed by an Arduino to display different colors and patterns. The array is mounted on a wooden base and encased in an acrylic box. A large button, easily pressed by the child with disabilities, changes the lighting pattern and display color. Figure 1 shows an early prototype of the LED-matrix.

In order to design the final LED-matrix, the three teammates took part in multiple levels of coordination, both inside and outside of class. First, Nick had to persuade his teammates of the merits of the LED-matrix. He did so by providing a detailed description of the project that he found online. In addition to agreement by the team, the project also had to be vetted by the class and the instructor. The team was required to present multiple times on their design throughout the semester including their initial design idea, a request for materials, and critical and final design reviews.

The materials for the LED-matrix were acquired both on and off-campus. Nick went to Home Depot to purchase acrylic, as well as to an electronics store to purchase an Arduino. They ordered an LED strip online from China. Maria purchased wire from the

HC electronics shop; Katherine found scraps of wood for the base from surplus in the basement of the HC. In her interview, Katherine remarked that it was important for her to know whom to contact for help and that she routinely asked the HC equipment manager for advice. Each material connected the students to another place, resource, or person.

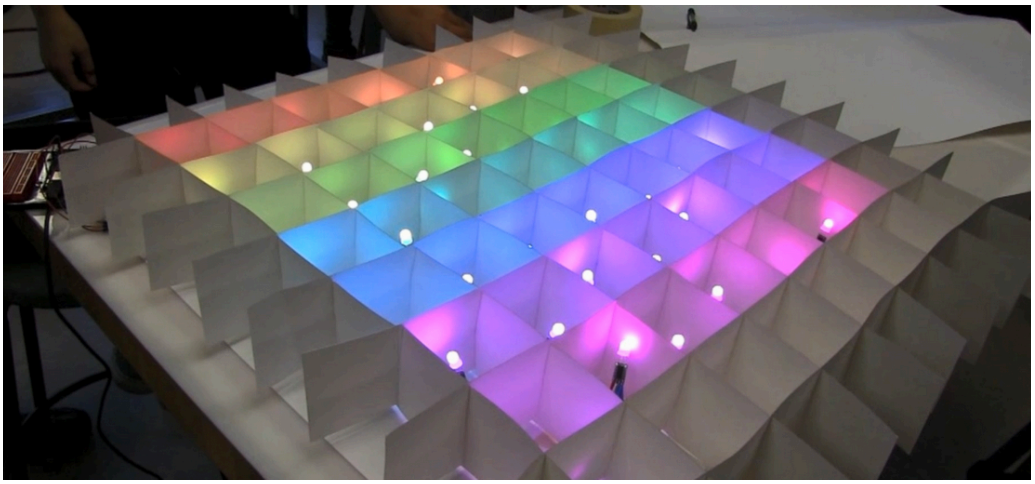

Figure 1. An early prototype of the LED-matrix in the HC technical skills-driven section

Katherine, Maria, and Nick leveraged resources in the HC to assemble their materials. Both the wooden base and acrylic box needed to be cut to fit the dimensions of the LED-Matrix. None of the team members were confident with their machining skills; Nick, referring to the machine shop manager, said, “I’m an idiot when it comes to machining. I don’t know what’s going on. He [the machine shop manager] helped us a lot with just basic stuff, like how to use the table saw.” Katherine spent many hours in the electronics shop soldering the LED strip. Because Nick had prior exposure to electronics he did not ask for much help when programming the Arduino, however, Joshua told us, “when it finally came down to programming the Arduino that we used, I just basically went to Tom [the HC electronic center manager] and was like, 'I have no idea what I'm doing. Help me out.' He helped me out through it all, and he was pretty excited to do it, so that was nice."

After the LED-matrix was constructed, the team had to coordinate with the class to mount the object in the playhouse. Additionally, the playhouse needed coordination to be displayed at the Design Exposition and then transported to the family's home. Several of the teams did not plan for assembling the playhouse for the Design Exposition, meaning they had to take it down and reassemble it multiple times. Joshua commented, "the final construction of it [the playhouse] took longer than we thought. Also, for taking it apart and then bringing it over to his house, the modularity of it, we should have designed that into our LED strips 'cause we had to take it all off."

The design of the LED-matrix involved the coordination of people, ideas, resources and tools: all of which extended beyond the classroom walls and, yet were informed by classroom practices. At every turn of the project, a different set of sociotechnical resources were leveraged. Understanding the design of the LED-matrix required an appreciation of much more than the materials and steps taken by individuals on the team. Any description of the design of the LED- matrix without an account of this coordination inside and outside of the classroom would be an impoverished account. This is significant not only for the description of the design, but more importantly for an appreciation of how instruction can be organized to facilitate, or not, networks of opportunities for students. The HC is a network of opportunity the extent to which is appreciated when compared to a section taught outside its confines.

Cognitive Theory-Driven Section: Sustainable Healthcare in the ILLP

The cognitive theory-driven section of ENGR1000 was taught by John, a tenured professor in Civil Engineering. John's syllabus stated that, "the objective of this course is to introduce topics related to decision making in engineering design." He further stated in his syllabus that he wanted students to get "an overview of the broad set of issues that influence engineering projects" as well as adopt the theme of "learning from the past." John organized his class to be primarily about theoretical principles of design. Each week he planned a lecture that presented an overview of a topic such as "ancient world design and engineering" and "modern engineering design." Alongside the lecture, John listed labs relevant to the week's topic. The labs were activities in which students engaged actively rather than workshops or guest lectures. Students were expected to complete two major projects each worth 30% of their grade. The projects were meant to reinforce theories of design and incorporate design thinking skills in favor of instantiating the complete design cycle of design, build, evaluate, and repeat; the focus was on the design and build components. Each project was to take about six weeks.

John had a co-instructor, Pam, a doctoral student in engineering with a master's in engineering and higher education; she had previously taught ENGR1000. There were no additional TAs for this class of 44 students. John's only planned guest lecturer was a friend, Mary, whom he asked to give advice on writing. Mary was a retired lawyer, who now blogged and was attempting to publish three novels she had written. John told the students that he wanted them to learn from a "professional" writer rather than an engineering educator because good professional engineers know how to write well. She worked with the class on three occasions over the semester to offer writing suggestions.

The section was specially organized to serve students participating in a newly formed living and learning program focused on international engineering challenges and the global demands of engineers: the international living and learning program (ILLP). In this program students lived in the same dormitory with a faculty mentor and attended shared classes. Living and learning programs attempt to integrate students' experiences both in and out of class by providing a community that allows for faculty and peer interaction, which is hoped to result in an academically and socially supportive living environment (Gabelnick et al., 1990; Lenning & Ebbers, 1999).

The ILLP section of ENGR1000 was not held in the HC; rather, it took place in a multi-purpose room on the first floor of the ILLP dormitory. The room looked much like a hotel conference room. It was one large room that could easily be modified into smaller rooms with room dividers stored in the walls. The tables and chairs were easily movable lending themselves to multiple configurations. The carpet and walls were neutral colors, with no distinguishing features. There were projectors on either side, but there were no computers, equipment, or tools. There were no spaces in the room for students to leave or store their things. Although the students lived on the floors above, the first floor felt public and open. There was a coffee shop with a small market open to all, and the classroom itself could be reserved by anyone affiliated with the university.

The ILLP was developed in part with the recognition that professional engineering is increasingly becoming an international endeavor. In their marketing materials, the ILLP cites that the top engineering firms earn over 50% of their income from international profits. There is a need, therefore, for students to have "global skills" such as knowledge of international telecommunications tools in order to collaborate with and lead international and multicultural teams. Students accepted into the ILLP are required to have proficiency in a foreign language, traveled internationally, studied abroad or have an overarching “desire to broaden their knowledge by experiencing international culture,” and want to understand how current information technology is driving intercultural communication. It is also stated that this program is for students who “want more from their education than technical skills” and that through this program they will develop a “clearly differentiated skill set above and beyond your technical skills.”

The ILLP section deemphasized the technical skills of engineering in favor of introducing students to a variety of types of decision making in the engineering design process. The syllabus stated that the course was designed for students to “obtain an appreciation of the overall issues that designers must address for engineering projects.” In an interview, Pam reiterated that she and John wanted students to negotiate definitions and meanings for their projects. The course was organized to examine multiple case studies while focusing on different theoretical principles of design. The syllabus looked very different from the HC section in that it only contained grading breakdown, schedule, and overall objective and course structure. There were no resources, people, or places listed. Rather than using a textbook, students were asked to purchase a contemporary book on design thinking, *Design thinking: process and methods manual* by Robert Curedale (2013), which emphasized the history and subject of design as well as explaining methods to achieve user-centered design. The overall philosophy of this section was very different then the HC section. The focus was on the theory behind design and “thinking like a designer,” rather than having an equal focus on the practice of engineering design as well.

Students were expected to develop two projects in the course, one introduction project and one innovation project. The overall theme for both projects was the "design of a sustainable community." Since this course was intentionally more exploratory in nature by design, it did not follow the same structure as the HC courses. For example, students were allowed to self-select their teams based on their interest within the sustainable community. There ended up being 10 teams with 3-5 students on each team. There were no explicit roles for the students on the teams; rather, tasks were decided amongst the team and then delegated to various members. Students worked on the first project for about the first ten weeks of the sixteen week semester. Students were then allowed to change teams for a final project the last five weeks of class. Towards the end of the term, the instructor had students vote on whether they wished to participate in the College Design Exposition. The majority of students elected not to participate, thus none of the class participated.

Since the ILLP emphasized the global demands of engineering, John decided to have sustainable global solutions as the theme of the class and the students would theorize how to design a sustainable community. At the beginning of the semester, John and Pam listed on the white board all of the elements they believed were necessary to build a successful community including: healthcare, education, food supply, and others. Each team then chose one of the different areas to be their focus for the semester. One team argued that security and defense were important elements of a successful community; John agreed and let them add this to the list and select this as their focus. We followed the healthcare team. The team consisted of Holly, Cassandra, Mackenzie, and

Patrick. Cassandra and Mackenzie were roommates, and they all considered each other friends.

John told the students that each team was going to develop a portion of a "townlet" or small sustainable community. In doing so they were to focus on the conceptual features needed for the community rather than the specific details. For example, he said they needed to account for lighting but not necessarily an exact number of lights. The course was structured so that students began with design theory with topics such as why learn from the past, ancient world design, and the design process. John would lecture on these topics and then have students engage in thought activities, which included a probing question that required students to ponder and discuss the reasoning for their answers. As part of the design thinking organization of the course, John emphasized that all designs have materials, expertise, and resources. He gave the students a list of materials and expertise. The materials included fresh water, natural gas, electricity, farm animals, glass, wood, among others; examples of expertise included understanding how governments functions, craft skills, professional skills, community influence, and transportation availability. John intended for students to debate and "win" a hypothetical material and expertise of their first choice. The students, rather than debating, organized a discussion based on their given focus and distributed the materials and expertise on what they thought would be most beneficial to each team. The healthcare team received fresh water and community influence.

The first four weeks of class were a combination of lecture and thought activities. An example of a thought activity was a question, "If you were going on a trip, what would be the top three things you would bring with you?" This would be followed by the class thinking individually at first, followed by a group discussion of why certain people chose certain items. At the end for the fourth week, John told the students he was giving them the "last piece of your puzzle," the location for their design. He brought in a topographical map of a nearby town to use as a model for the students' hypothetical community. The original intention was to make a replica of the town on an eight-foot by four-foot board in which each team would design a one-foot by one-foot section. Each team had to ask for a particular part of topography (i.e. flatland, access to water, in the mountain or valley), and they would build their portion of the sustainable community there. After a few weeks, John decided that it would be too difficult to scale all of the different projects, so each team was to make a model on a separate one-foot by one-foot board.

The healthcare team decided to build a model of a hospital. Pam was tasked with getting supplies for the model. She brought the team foamcore, exacto knives, tempera paint and a drop cloth; she also bought and gave to them a miniature toy helicopter and ambulance. For the next five weeks, students alternated between lectures given by John and working on the model. Holly, Cassandra, Mackenzie, and Patrick claimed the space in the hallway in front of the meeting room. They would spread out the drop cloth to cover the hallway carpet they were working on, cut pieces of foamcore, and paint them while talking about their social lives and other classes. Figure 2 shows the hospital model being worked on in the hallway. Because the classroom was an all-purpose room available to be scheduled by anyone on campus, the doors remained locked when shut. Therefore, the team would prop open the door so that they did not have to knock to re-enter. While the team painted their hospital, students from other teams would often come to ask to borrow supplies such as a hot glue gun or scissors. When the team finished class each day, they took the project to Cassandra and Mackenzie's shared dorm room.

At the end of the sixth week, the manager of the HC electronics center, Doug, gave a guest lecture on circuits. After this lecture, John changed the requirement of all models so that they had to have at least one LED light. Holly and Mackenzie then asked John's permission to go to the HC to get LEDs and resistors, while Patrick and Cassandra glued the hospital parts together. When Holly and Mackenzie returned, the team realized they are out of glue. Pam told them they can get glue at the HC. Mackenzie laughed saying they were just there. Rather than walk back, Mackenzie started calling other students to see if any of them were at the HC.

Figure 2. Construction of the hospital model in the cognitive theory-driven section in the ILLP

More than halfway through the semester, all of the teams presented their models of the townlet. In addition to the replica of their portion of the sustainable community, teams were required to present on the theoretical considerations of their design. The healthcare team wrote in their documentation that, "sustainable healthcare in the community includes three main components: the physical design of the town's central hospital, partnerships both within and outside of the community, and programming within the community." The team was reflective about what sustainable healthcare means, as such they discussed at length how they would focus on health education and wellness initiatives including organizing a 5k run for community.

After the initial project was presented, students were told that they would need to develop a technological solution to a problem in their chosen field. The teams were allowed to reorganize themselves, but the healthcare team decided to remain the same. After a week of deliberating, the healthcare team decided to develop a water bottle that digitally displayed how much water you have consumed, citing that 75% of Americans are chronically dehydrated. The final prototype and presentation was to be submitted three weeks after they presented their initial idea. The team's initial idea was to use a magnetic or light sensor with a flow meter in the mouthpiece of water bottle. Upon realizing they had limited time and understanding of electronics, the team decided to create water bottle that lights up LEDs based on Doug's electronics presentation. Even though Cassandra couldn't remember the HC electronic center manager's name, she recalled hearing in his workshop that water can complete a circuit. Their final design lit up one LED each time the water bottle was filled. When the water bottle is filled three times, the person has reached the recommended consumption of 104 ounces. The team presented a water bottle attached to an Arduino with three LEDs that light up and deemed the project a success. Patrick, in his final writing assignment called the project a "success" even though the water bottle was subject to malfunction including electrocution, stating, “in spite of all of these shortcomings, I believe that we achieved quite a bit considering our limitations and constraints” and “I gained some insight into the world of electrical engineering and Arduinos.”

The two projects the healthcare team designed represented the coordination of people, tools, and resources. John purposefully organized his section to privilege the reflective thinking that goes into design, therefore, the model hospital served as a representation of the ideas that the healthcare team thought were necessary to keep a sustainable community healthy. In order to define “healthy,” Mackenzie and Patrick used the internet to generate ideas on what health means. The resources needed to construct the hospital were provided by Pam with a few being obtained from the HC. John, in asking a professional writer to present in the course, was providing his students’ with a resource John valued as an engineering professional: writing. Mary reviewed the teams’ drafts and provided suggestions. When John asked Doug to present on LEDs in the classroom, he was providing another resource to his students. The healthcare team could not have presented their water bottle prototype without the assistance of Doug.

For both sections, we illustrate how the design of an object is a product of sociotechnical coordination, and how design instruction is also complex sociotechnical system that connects students to resources inside as well as beyond the classroom. There are many facets of the ILLP section that can be compared and critiqued with that of the HC sections; we knew that there would be differences prior to beginning our observations. However, it is only when we apply a heterogeneous framework to each that we can begin to articulate the consequences of these differences.

Findings and Discussion

We report three major findings after observing, analyzing, and comparing the two sections of first-year engineering design courses using a heterogeneous engineering perspective. The first finding is that taking a heterogeneous perspective on design instruction articulates the consequences regarding how instructors favor certain aspects of design over others. The second finding is that the introduction of actors (i.e. space, people, resources, tools) in the course plays an important role in how students learn design (Law, 1987). The third finding is that boundary objects (Star, 2010) created by the teams in the courses act as an organizing tool that mediates sociotechnical activities in which students engage. The three findings together illuminate the need for a heterogeneous perspective on design instruction. Instructors must be cognizant in organizing their courses, through aspects like introduction of actors and creation of boundary objects, in order to better prepare their students for future engineering design endeavors.

Finding 1: A heterogeneous perspective articulates consequences of types of design instruction

In this paper, we summarized two sections of first-year design that are considered identical on paper by the university, and yet are drastically different in practice. Each section was organized with a different underlying philosophy of design. The HC section emphasized technical skills and practice, while the ILLP section emphasized cognitive theory and meta-reflection. These different design philosophies, taken from images in the respective textbooks, can be seen in Figure 3. The HC section (Figure 3, left) shows the idealized linear steps (green outer arrows) required to complete a design project and the actual steps (black inner arrows) usually required to finish the design. This standalone image shows that building, testing, and evaluating a prototype is essential to finishing the project, thus highlighting the importance of a hands-on approach to design. The ILLP section (Figure 3, right) shows that design is a balance between understanding and incorporating perspectives from people, business, environment, and technology. This image emphasizes that design is a thought-driven process, requiring empathy, understanding, and collaboration of multiple factors each which often have competing goals.

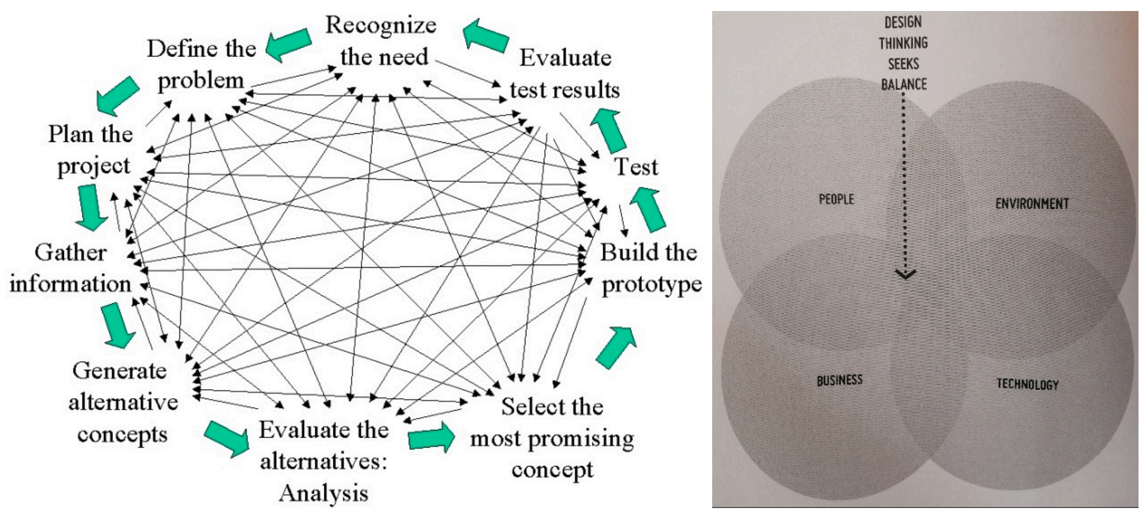

Figure 3. (Left) The design philosophy from the technical skills-driven section's textbook in the HC. (Right) The design philosophy from the ILLP cognitive theory-driven sections' textbook.

The juxtaposition of a section emphasizing the cognitive and theoretical principles of design like the ILLP section with a section emphasizing the hands-on application of design such as the HC section is intended to show that design is always bringing into alignment theory and practice. In the technical skills-driven section, the design philosophy of "design, build, evaluate, repeat" is often reflected in the sophistication of the final product. In the cognitive theory-driven section, John and Pam chose to minimize the significance of a final design product in favor of allowing students to explore the thought processes that inform design. Pam said in describing the ILLP section, "The content, and the intention [of the course] was that it is basically had the same learning content about the design process [as the HC sections]. And about the iterative nature of design where you come up with a solution…Even if you just get lost. Lost in revisions and never get to an actual product. But part of the design process is to learn that you probably didn't think of everything you needed to think of right up front." The students, however, were still required to create an object that represented this thought process.

A heterogeneous perspective on design instruction shows how both of these sections favored certain aspects of design – the HC favored building while the ILLP favored thought-driven activities. Either is consequential depending on the networks students are able to connect to. We believe that since design is a heterogeneous process, instructors should take a heterogeneous approach to design instruction. This would entail explicitly recognizing which aspects of design, theory or practice, are privileged during instruction, while being mindful that engineering design is always both.

Finding 2: Introduction of actors impacts how students learn design

Learning to become an engineer is a social process in which some students are actively pulled in while others are pushed out (Stevens et al., 2008; Wenger, 2000). We argue that students get connected, or not, to particular sociotechnical systems that support their learning of design through their design courses. The introduction of actors (e.g., space, people, tools, resources) creates trajectories into networks that will be differentially taken up or disregarded as students progress through their undergraduate years. Our research demonstrates that the organizing features of design instruction, including the coordination of space, people, and resources, strengthen certain ties while dampen others. Therefore, engineering educators should be mindful regarding the decisions they make regarding how they organize for classroom projects as this can have a sizeable impact on how the students learn design. To illustrate this point, we describe the network of opportunities created in both the HC practice-driven section and the ILLP thought-driven section.

In an effort to exemplify the connection to actors in the two sections, we have shown a timeline of the two classes with indicators for when key actors were introduced in each course in Figure 4. The HC section had considerably more introduction to people, spaces, and resources than the ILLP section. We argue that each person and resource represents a possible opportunity for students to make a connection in the practice of engineering. Although some students may not make a connection with a particular resource, each resource represents a potentially different network that students could become tied or "pulled-in."

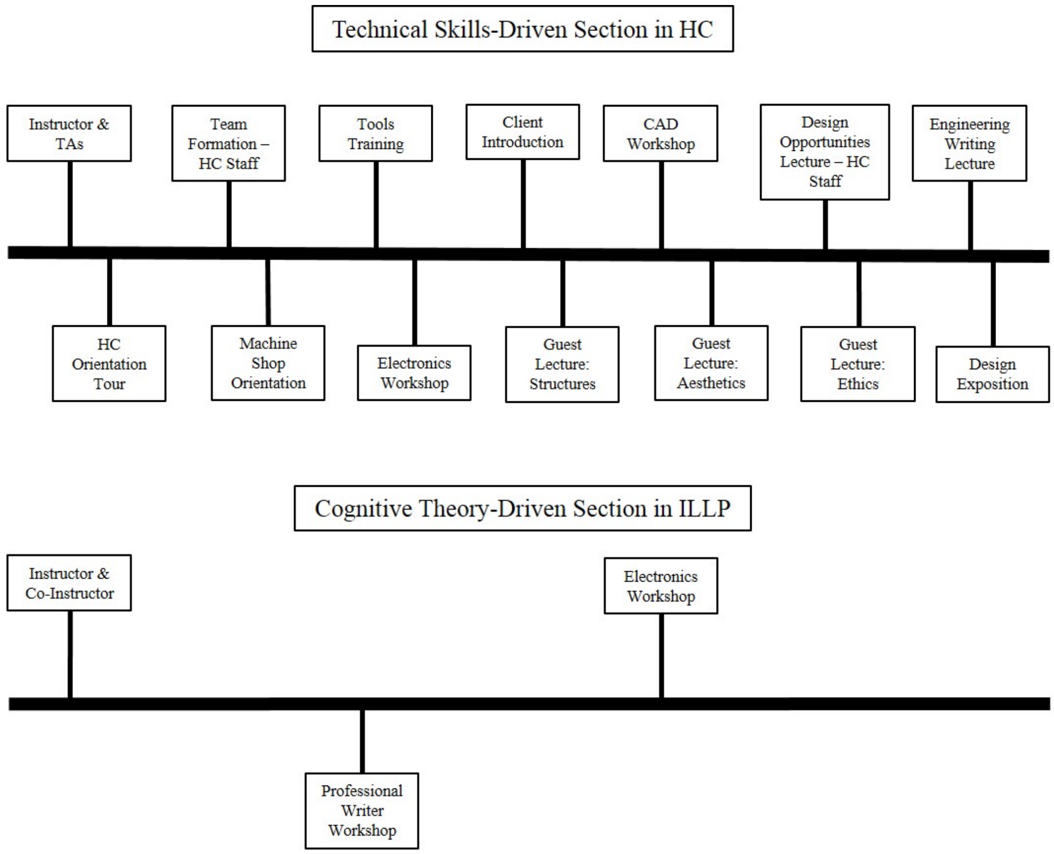

Figure 4. Introduction of key actors in each course

A prominent feature of the ILLP section was that it was removed physically from the HC. Figure 5 illustrates distance between the respective buildings; they are 0.7 miles from each other on the expansive campus. Next to each building are listed some of the key spaces in each location. This distance between the buildings and the respective spaces within them appeared to affect the relationships students from the ILLP section were able to develop with HC staff. Often the ILLP students were documented in field notes asking permission to leave their classroom to visit the HC. Once there, the ILLP students did not know who to ask for what resources, were unable to name the different staff members, and felt ignored by HC staff. Students in the HC section were equally likely to praise as to offer criticism of staff, but they were able to specifically name the staff at the HC. HC instructors expected students to leave during class and interact with HC staff; the HC was thought of as an extension of the classroom. Furthermore, HC staff privileged students in ENGR1000 over other students. An HC staff member giving the tour of the manufacturing center told Camilla's student, "You students have priority. Even if a senior is working you can tell them you are an ENGR1000 student and they should let you use it." However, it should also be noted that since the ILLP was located in the same building as the dormitories of the students that class was able to build a stronger community bond between the 44 of them. This tight-knit group has the chance to use the relationships made in this environment later in their engineering career.

Figure 5. Location of each course and spaces

John organized the ILLP section based on his experience as a professional engineer. He often made comments about how he hired engineers who could write, one of the reasons he chose to have the professional writer provide a guest lecture. He also explained to one of the researchers that he believed employers do not hire engineers based solely on technical skills anymore. He said, “Anyone can have skills, employers want people who know how to think.” John reinforced the ideals of the ILLP in that engineers will need to know how to think in a global world. From his view, encouraging students to develop critical thinking skills, as well as foreign language skills in the ILLP, is valuable and will potentially open different opportunities for these students. It is difficult, however, to see how these thinking skills alone lead to greater opportunity without being tied to social resources or networks that value them. John presented one vision of what professional engineering entails from his perspective as a professional civil engineer, a vision that not all students will attain or desire. Although he did hire Mackenzie as a part-time student in his lab, the organization of the ILLP section did not make visible the ways in which this approach to design would be valued. One goal of the HC sections is to expose students to the myriad of types of engineering and roles available to future engineers. The ILLP section had two guest lecturers, the professional writer and Doug, the HC electronics center manager. The HC sections had guest lectures and workshops on electrical engineering, CAD, engineering structures, engineering writing, environmental engineering, machining, engineering ethics, and more. The students in the HC received a multiplicity of images of what engineering is and can be; and, thus, have a multiplicity of horizons of opportunity through which to imagine their future selves.

Finding 3: Objects of Coordination (Boundary Objects) Mediate Sociotechnical Coordination

One final organizing feature we recognize is the creation of boundary objects by the design teams (Star, 2010). We consider these boundary objects to be *objects of coordination*, which mediate the sociotechnical activities in which students engage. By referring to boundary objects as 'objects of coordination', we are emphasizing the ways in which boundary objects represent both materiality (an object) and the "invisible work" by which the object becomes tailored to local use.

In HC sections, the object of coordination is most often the prototype of the final design, here being the playhouse and LED-matrix. While in the ILLP section, the boundary object was the model of the hospital, the LED water bottle, and the supporting documentation defining healthcare for a sustainable community. The prototypes as objects of coordination for the HC section served as a more robust conduit for ideas, materials, and relationships beginning with the idea phase and culminating at the Design Exposition. For example, in the creation of the LED-matrix, the students interacted with the internet, each other, an electronics retailer, a hardware store, the electronics lab, the machine shop, the laser cutter facility, the instructors and TAs, as well as coordinating with the entire class and the family for whom the playhouse was being built. They then presented the LED-matrix at the Design Exposition, which made the team visible to an audience of engineering educators, professionals, and the public creating further potential connections for the students. At the Design Exposition, this object of coordination also acted as a communication tool between various networks – the engineering teams and various networks of people present.

The sustainable community model, LED water bottle, and documentation for the ILLP section also served as a representation of ideas, materials, and relationships in a similar way. The model of the hospital represented the coordination between the team members, the instructors, the thought activities, and sustainability research. Pam, the co-instructor, procured all of the design supplies and delivered them to the team. The students then had to negotiate with one another to determine who would receive which supplies. However, neither final product, the hospital model nor the LED water bottle, were showcased in Design Exposition, thus limiting both visibility and further coordinating activity.

The design objects represent not only the theory and practice of design; they are heterogeneous organization of people, tools, and resources and the result of a sociotechnical process. In engineering education, the object of design, whether a prototype or comprehensive paper, is a tool of instruction that connects students to sociotechnical systems to which they may not have otherwise been a part. How an instructor organizes for the implementation of these objects of design is consequential for how students learn design and, thus, learn to become engineers.

The objects of coordination in a first-year projects design class serves the same purpose as the bridge in Suchman's (2000) theory of organizing alignment. The representation of a bridge, or its prototype in multiple forms, was the object that coordinated all of the activity; in the end the building of the bridge itself was outsourced. Therefore, since the bridge was outsourced, the prototypes then acted as the objects of coordination for the team. The prototypes then facilitate the organizing work connecting people, resources, and tools. In this way, engineering educators should consider how their object of coordination in first-year design classes is organizing activity. The object of coordination can take on multiple forms from a representation of "design thinking" or a physical prototype that through its complexity reflects the *sociotechnical* processes required to create it.

Conclusions and Recommendations

The design of any object is an intentional activity that can only be fully explained by attending to the heterogeneous organization of sociotechnical systems (Suchman, 2000; Trevelyan, 2010; Williams, 2002). We argue this is true for the organization of first-year projects courses as well; there will always be intentions alongside contingent factors. Because the practice of engineering is heterogeneous, we argue the pedagogy should be as well. With this in mind, engineering educators can and should be purposeful in the intentional organization of first-year design courses while recognizing that people, materials, and ideas all matter and are inextricably combined through an object of coordination.

We recommend that engineering educators should not only consider the ways in which to introduce students to design theory, but also the tangible tools of design including the physical space where design work occurs, the availability of and proximity to material and technical resources, and the availability and proximity to personnel resources. We maintain that specification of the demands and constraints of an object of coordination reflects the extent to which an instructor has been thoughtful in the organization of their course. When students are expected to avail themselves of multiple ideas, people, and materials, while also demonstrating sound design theory, they become part of the engineering sociotechnical systems we want them to be.

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CHAPTER THREE

An Argument for a Spatial Analysis of Learning

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Abstract

In this article I present spatial analyses of two students becoming engineers. I argue that this spatial analysis provides a new lens for understanding the phenomena of learning to become an engineer, contributing to both general theories of learning as well as methodological approaches to studying learning. In order to frame these student case studies, I discuss the historical foundations of socio-cultural approaches to learning and develop a foundation for researching and interpreting learning from a spatial perspective. I demonstrate how a spatial approach to learning enables the concepts of *disciplinary practice, equity,* and *transformation* to be held together during our research of and organization for learning.

INTRODUCTION

Why pursue a spatial analysis of learning given the work already arguing for space-related views of learning? Under this broad umbrella I include situated accounts of learning (Lave & Wenger, 1991), expansive views of learning (Engeström, 2001), and views of learning that not only recognize change over time but across settings as well (Cole, 1996; Lave, 1996, Barron, 2010). The argument that I develop in this article is not for a new theoretical approach to studying learning, but rather for a greater appreciation of the concept of space within our theories. An in-depth understanding of space undergirds what we know about learning.

The empirical research on which I report is located within the context of engineering education, with a particular emphasis on understanding the role of design in undergraduate curriculum: how design is organized for by disciplinary administrators, enacted in the classroom, and experienced by students. As part of this process, I observed and interviewed a group of student engineers that also participated in a student club created to provide professional development, networking, and social activities for LGBTQ (lesbian, gay, bisexual, transgender, and queer) students. On the surface this article may appear to be primarily about engineering, gender, sexuality, and heteronormativity; these concepts, however, mediate the analysis of the spaces of engineering. In order to investigate the situated, spatial nature of learning within a discipline, the defining concepts of the discipline, such as *design* in engineering, must be interpreted by examining their relationships with other concepts defined and shaped within that discipline. I chose to explore how gender, sexuality, and heteronormativity are framed within the discipline of engineering.

In addition to providing a lens for interpreting the discipline of engineering, the concepts of gender and sexuality are often taken to be constitutive properties of individuals, fundamental to how we act and participate in the world. In recognizing that learning is a relationship between an individual and a given practice (Lave & Wenger, 1991), taking a concept like gender, for example, and looking at how disciplinary practices are related to it, uncovers the ways in which gender is made consequential for individuals in the practice. Engineering educators continue to investigate and attempt to rectify the underrepresentation of women in the field. Understanding how practices make gender, and sexuality, consequential is an issue of equity. The spatial analysis developed in this paper shows how certain ways of being are produced and get built into the spaces of engineering enabling who becomes an engineer and who does not.

In the learning sciences, researchers have studied disciplinary practices from an equity perspective in order to support the transformation of practices (Tabak & Radinsky, 2014; Tan & Calabrese Barton, 2010; Barab, Dodge, Thomas, Jackson, & Tuzun, 2007; Nasir, Roseberry, Warren, & Lee, 2006). Again, I chose to include a group of LGBTQ student engineers in my study because they were actively trying to change and transform engineering education and workplaces to become safe and inviting spaces for LGBTQ engineers. A spatial analysis shows the potential places and moments for disciplinary transformation. This article demonstrates how a spatial perspective of learning affords new opportunities for investigating and interrogating disciplinary practices, how practices are organized to support certain ways of being but not others, and ultimately how educators and learning designers can facilitate new ways of being in the world.

DIALECTICAL MATERIALSIM IN LEARNING AND BECOMING

Learning involves a relational change between an individual and a community or activity system (Lave & Wenger, 1991; Cole 1996). The relational nature of learning is tied historically to Vygotsky's (1978) development of a theory of psychological processes that recognized the embodied mind as part of the material world. As such it is important to understand the grounding principles of Vygotsky's thought, and in particular his use of the Marxist doctrine of dialectical materialism to understand the mind in society. My spatial analysis is similarly rooted in dialectical materialism as it has been utilized by Lefebvre (1992). I present how both these theorists adopted this core concept in an effort to understand the subjective experience of the individual in an objective, material world. Vygotsky's legacy left an enduring focus on the historical and temporal nature of being; Lefebvre's project was to offset the prioritization of time by demonstrating the equally spatial nature of being. I am showing how adopting this spatial perspective increases our understanding of learning within a discipline.

Dialectical materialism is both a method and a theory employed by Marx to understand the structure of society in order to overthrow capitalism. In overcoming the idealism/materialism dichotomy, Marx gave primacy to matter or material reality, while the mental reflection of material reality was secondary or derivative. Accordingly, things exist in the world, but an understanding of things requires a dialectical method that considers things in their totality, including their movement, change, and interrelation as well as their contradictory and opposite sides. Things do not exist bounded with innate characteristics and fixed properties, but, rather, are in continual states of becoming and transformation. Knowledge of an object is only accomplished by examining how it stands in relation to other objects, but these relations are not stable or static, they are dynamic. These relations or processes of becoming are what define the object; they are not a byproduct of the object. Our inquiry, therefore, should be on these processes, for this reveals laws of societal development.

Vygotsky's theories of human development have generally been taken up in isolation from the Marxist roots in which they are grounded, but are in no less indebted to them (Fu, 1997, Wertsch, 1985). Vygotsky argued that you could not have a science of psychology by only examining the objects of inputs and outputs or the stimulus/response theories of behaviorists. He wrote, "we need to concentrate not on the *product* of development but on the very *process* by which higher forms are established…for it is only in movement that a body shows what it is" (Vygotsky, 1978, p. 64-65). The ways in which 'higher forms are established' are through interaction with the social world. Human development is a process of internalizing the social activities and interactions in which we engage. Drawing on dialectical materialism in which the material world is primary and our understanding of it secondary, Vygotsky argued that the social world precedes our understanding of it. Concepts, objects, and tools have meanings created in the cultural communities in which they exist, and children or learners, come to understand this meaning through participation and activity with the community. Participating in a community or activity system is not only a process by which people come to understand the world, it is the process by which people themselves get defined. "We may say that *we become ourselves through others* and that this rule applies not only to the personality as a whole, but also the history of every individual function" (Vygotsky, 1981, p. 161).

Implicit in the concepts of ‘process’ and ‘becoming’ is change; development is a process of change. Vygotsky maintained that the dialectical method ‘demands’ that something must be studied historically in order to study processes of change (1978, p. 65.). Subsequent generations of activity theorist further embraced the temporal and historical aspects of learning to such an extent that their approaches became known as ‘cultural-historical’ rather than ‘sociocultural’ (Roth & Lee, 2007). This distinction, although subtle, is significant for why an argument for a spatial analysis of learning is needed to balance the over-emphasis of temporal theories of learning. If learning is fundamentally social, as it is a relationship between an individual and her cultural community, then the social should be interrogated for its constitutive properties which include both time and space. Space is implicit in dialectical materialism, which seeks to understand an object’s *movement* and *relation* to other objects. Space, therefore, is equally important in understanding social reality as the concept of time (Lefebvre, 1992). This is not to deny that social practices have a history and temporality but, rather, a thorough understanding of social reality requires an appreciation of both time and space.

In *The Production of Space* (1992), Lefebvre asks, "What is the mode of existence of social relations?" (p. 401). According to him social relations cannot be understood solely through a form, function, or structure, rather they can only exist within some "underpinning". "Space" is his underpinning. Space, however, is much more than the basis for social relations even though it is necessarily the setting for human actions. Space produces the ways in which people are able to act in the world, and the ways in which people act in the world produces space, “(social) space is a (social) product" (Lefebvre, 1992, p. 26). Again, like Marx and Vygotsky, Lefebvre draws on dialectical materialism to show how the investigation of the processes or production of space, not the object of space, defines social reality. As such space is not a singular object, but can be analyzed from three different axes including how space is perceived, conceived, and lived. Furthermore, social space can be understood in 'trialectic' moments of spatial practice, representations of space, and representational spaces. I further define Lefebvre's theory of space below, and similar to dialectical materialism, I use the spatial trialectic as both a theory and method in understanding learning in the disciplinary practice of engineering. The trialectic method is a useful tool in both uncovering how the discipline is defined through organizational practices and how these organizational practices can be transformed.

Transforming disciplinary practices requires a commitment to understanding both how practices *ought* to be (Penuel & O'Connor, 2010) and how we can design for greater equity in learning (Gutierrez & Vossoughi, 2010). Engineering education provides a unique context to examine gender equity in that it has been historically, and continues to be, a discipline in which women are underrepresented compared to men despite concerted efforts to rectify this (Tonso, 2007). Gender is also an interesting construct to explore within the trialectic framework. Dialectical materialism gives primacy to matter. The material world, including bodies, can only be understood in a dialectic manner; sex and gender are to be examined via the processes that produce them. Sex is not a byproduct of the body, but is rather a process by which a bodily norm is assumed and appropriated (Butler, 2011). I maintain that the trialectic method helps us to examine these processes, and specifically these processes within a discipline where particular types of bodies are underrepresented.

The spatial trialectic that I develop in this paper seeks to examine how disciplinary practices become bounded, how individuals are both expected and prohibited from participating in these practices in particular ways, and moments of opportunity when educators and designers of learning can encourage change and transformation.

EQUITY AND TRANSFORMATION IN DISCIPLINARY PRACTICES

Learning is a process of becoming (Wenger, 1988; Lave & Wenger, 1991). As such, learning creates new ways of being in the world, enabling learners to both perform in new capacities as well as be recognized by themselves and others as having negotiated new identities. Social practice theories of learning and development examine the changing nature of both the practice and the individual by arguing that persons and practices are mutually constitutive (Packer, 2010). Furthermore, dialectical materialism emphasizes how each can only be understood relationally in their continual states of becoming. The spatial trialectic provides a means for interrogating these relationships. Before analyzing said relationships, in this section, I examine how disciplinary practices have been conceptualized as well as theories of equity and transformation within the disciplines.

Sociocultural theories of learning prioritize communities and activity systems as units of analyses (Lave & Wenger, 1991; Rogoff, 1994; Cole, 1996). A discipline is often thought to be a particular type of community or activity system, characterized by particular types of beliefs, behaviors, and perceptions. One way in which a discipline is bounded is by its epistemic practices including what counts as knowledge within the discipline and what methods are appropriated to generate knowledge. The value of both, knowledge and methods, varies across disciplines and within disciplines over time (Kuhn, 1970). I take a broader view of disciplinary practices in that they regulate more than epistemologies. Drawing on Foucault (1995), a discipline coordinates behaviors and attitudes by imposing homogeneity through normalization. Beliefs and actions appear as either normal and conforming to the discipline, or different and outside the discipline. Taking a broader perspective of disciplinary practices enables researchers to investigate not only knowledge practices of the discipline such as how certain types of performances are deemed disciplinary knowledge (Stevens, O'Connor, Garrison, Jocuns, & Amos, 2008), but also the ways in which individuals develop disciplined vision and perception (Goodwin, 1994; Stevens & Hall, 1998), and cultivate disciplinary identities (e.g., Tan & Calabrese Barton, 2008; Wortham, 2006; Boaler & Greeno, 2000; Gee, 2001).

Although disciplinary identities are in part cultivated by instructional practices, when disciplinary learning is understood only within the context of classroom instruction, the cultural and historical aspects of identity development are overlooked (Holland, Lachicotte, Skinner, & Cain, 1998, Nasir & Saxe, 2003, Brown, 2004.) We know both that individuals bring particular ways of seeing, valuing, and acting in the world from their cultural communities and families (Gonzalez, Moll, & Amanti, 2005), and that disciplinary learning is not isolated to classroom practices, out-of-class experiences impact understanding, expertise, and identity (Bell et al., 2009; Vossoughi & Gutierrez, 2014, Polman & Miller, 2010). Taking too narrow a view of disciplinary identity development can lead to false assumptions that learning in a discipline is value-free and can occur with a one size fits all, singular approach (Medin & Bang, 2014).

Understanding the extent to which disciplinary practices enable or constrain certain identities is an issue of equity. Disciplinary practices are imbued with disproportional degrees of power in relation to cultural practices (Nasir, Hand, & Taylor, 2008). Negotiating a disciplinary identity is impacted by identity markers including race, culture, and gender (Tan, Calabrese Barton, Kang, O'Neill, 2013; Nasir, 2011; Carlone & Johnson, 2007, Nasir & Saxe, 2003). Our task as learning scientists is not simply to determine the ways in which identity markers are made consequential in practice, but to recognize our role in designing for possible futures and outcomes that promote broader justice and participation (Gutiérrez & Jurow, 2014; Jurow & Shea, 2015). For example, Gutiérrez's notion of *thirdspace* (2008) is an attempt to create opportunities for new forms of activity that not only support disciplinary knowledge development, but also reorganize practices to shift what counts as knowledge and create possible futures in particular for marginalized communities. However, questions remain as to what other aspects of individual identity, such as sexuality, are presented as not pertinent to disciplinary identities yet greatly impact how disciplinary identities are negotiated and taken up, how are disciplinary practices organized for this to happen, and in what ways can disciplinary practices be transformed to mitigate seemingly, yet falsely, conflicting aspects of identity. The spatial trialectic, with its attention to the perceived, conceived, and lived, is a tool to investigate these questions.

LEFEBVRE'S CONCEPTUAL TRIAD OF "SPACE"

Lefebvre's conceptual triad offers a useful scheme to understand how space is socially produced, and since learning is a social phenomenon, this scheme provides a tool to develop an integrated account of learning that combines the social, physical, and mental. According to Lefebvre, space is best understood by recognizing its three different aspects that exist dialectically with one another. The three aspects that form the "conceptual triad" are spatial practice, representations of space, and representational space. The triad is simultaneously understood as perceived, conceived, and lived. *Spatial practice* embodies the spatial relationship between objects and products, or the cohesive patterns and places of social activity. Spatial practice includes places set aside for work, private life, and leisure. It is how space is perceived and can be thought of as physical space. *Representations of space* are constructed out of symbols, codifications and abstract representations. Representations of space are conceptual, inherently ideological, and are the space for scientists and urban planners who produce maps and models of how to conceive of and coordinate space. Lefebvre suggests this is the dominant space in society and can be thought of as mental space. (1992, p. 38-39). *Representational Space* is symbolic space that emerges as a result of our lived experience and our interaction with images and symbols This is the space of artists, where the imagination seeks to appropriate and change space. It can be thought of as social space. For conceptual lucidity, I refer to Lefebvre's spatial trialect as *spaces of practice, spaces of coordination,* and *lived spaces of transformation*. I take each in turn.

Spaces of Practice

"Spaces of practice" emphasizes how spatial practice represents "production and reproduction, and the particular locations and spatial sets characteristic of each social formation" (Lefebvre, 1992, p. 33). Encompassing physical space, spaces of practice embody the spatial relationship between objects and people interacting with these objects. Similarly, I take spaces of practice to be the places where people engage with each other and objects taken to be significant for engineering as disciplinary practice. Salient features of these spaces are the tools and materials available with which participants can interact. These places include buildings, classrooms, study rooms, machine shops, and electronics labs. These are the places where students are classes being "disciplined" into the practice of engineering (Stevens & Hall, 1998). In addition to the material objects and tools in these spaces of practice, students interact with the people and the representational practices of engineering education. By this, I mean that students are learning to participate in the communication and reasoning practices that are part of engineering education (Hall & Stevens, 1995).

Spaces of Coordination

"Spaces of coordination" underscores how representations of space, such as maps, plans, and models, become prescriptions for how space is to be experienced. Lefebvre argues that planners and designers develop systems of 'verbal signs' to direct and organize spatial relations (p. 39). I include instructors, administrators, and engineering education theorists as the planners and designers of engineering. Lefebvre suggests that this is the dominant space insofar as the knowledge, logic, and ideology of a society, or in this case a discipline, are manifest. Representations become the measures by which claims of knowledge and truth are evaluated. Spaces of coordination include the places where official representations of engineering are propagated and circulated (Latour, 1987).

Lived Spaces of Transformation

The final third of Lefebvre's triad is *espace vecu* or lived space. This space has been translated as "representational space" (e.g., Nicholson-Smith, 1992) and "spaces of representation" (e.g. Soja, 1996), which is not to be confused with representations of space. For conceptual clarity, I refer to this space as "lived spaces of transformation" in order to capture the simultaneity of transformation as a lived experience. Lived space, according to Lefebvre, is "directly *lived* through its associated images and symbols, and hence the space of 'inhabitants' and 'users'" (1992, p. 39, emphasis original). This is the space where social relations take place and where we actively experience space in everyday life by experiencing moments of presence. Lived space gives meaning to, but does not subsume, perceived and conceived spaces. As the space where imagination takes hold, it is a space where ideals and social movements begin. It is the space where history is deciphered and made. Lived spaces of transformation in engineering are the spaces where students begin to understand themselves within the discipline, and act according to that understanding.

Space as a concrete abstraction

Fully conceptualizing space requires an appreciation of it as a "concrete abstraction." Time, also, is concrete abstraction. In the case of temporality, time as a concept does not reflect how individuals come to know time. Abstract time is measured physically by a clock, and, yet, experienced in moments. Time is thus a representation that is neither completely abstract because it is mediated by a physical object, nor is it representative of how time is experienced or lived. Likewise, space cannot be captured purely by how it is represented or conceived, it must be equally understood for how it is lived. Social relations, therefore, exist in time and space as concrete abstractions. The conceptual triad of space, the perceived, conceived, and lived, is intended to capture both the material and mental experience of social reality.

To understand how all three aspects of space exist dialectically together, imagine an engineering design classroom. The classroom is located in a building, on a campus, in a particular location. There are objects such as tables, computers, and worktables. The room itself is the container of spatial practice: the chairs are to be sat in, the workstations worked at. Engineering educators, however, designed the classroom along with planners and architects. The representation of this space exists in the blueprints and expectations of its planners, including course syllabi and other artifacts of engineering education curriculum. Classes conducted in this classroom become part of the representational space that creates the lived, social space for students learning to be engineers; engineering students experience moments of who they will become and how transformation unfolds. All three aspects must be taken into consideration in order to capture the social reality of the space: the perceived, conceived, and lived. I capture the three aspects in engineering education by analyzing its spaces of practice, spaces of coordination, and lived spaces of transformation.

LEFEBVRE'S TRIALECTIC IN LEARNING RESEARCH

The "spatial turn" in the social sciences continues to gain momentum (Soja, 2000). In addition to critical spatial perspectives in educational research (e.g., Bright, Manchester, & Allendyke, 2013; Leander & Sheehy, 2004), Lefebvre's concepts are being adopted by learning scientists to further explain and design for learning (e.g. Vadeboncoeur, Hirst, & Kostogriz, 2006). As an inclusive perspective of learning, Lefebvre's theory is being used to understand the relationship between local educational practices and their connections to broader global phenomena by thinking beyond the classroom as a container and looking at our assumptions of boundaries (Leander, Phillips, & Taylor, 2010; Kostogriz, 2006). More often, however, one aspect of the trialectic is highlighted to help further investigation of learning. For example, "lived space" becomes a framework for understanding classrooms and other learning environments (e.g. Ma & Munter, 2014; Hirst & Vadeboncoeur, 2006). Similarly, representational practices like mapping have been shown to be a powerful tool in connecting students to place and supporting spatial literacy and spatial justice (e.g., Taylor & Hall, 2013; Rubel, Lim, Hall-Wieckert & Sullivan 2016). When one aspect of the trialect is not being foregrounded, Lefebvre's appreciation for *both* space and time as being constitutive priorities of our social world is emphasized (e.g., Leander, 2002). The research I report on continues the use of spatial analysis to investigate learning with the guiding question: what are the affordances of using Lefebvre's spatial framework as both a theory and method of study? Instead of isolating one aspect of the trialectic, I use all three as a method of investigation into engineering learning including its disciplinary practices, where those practices are conceived, and where the moments of transformation are both possible and actualized. Similar to dialectical materialism, I employ the spatial trialectic as both a theory and method.

RESEARCH DESIGN

The data presented in this article was collected from two separate but overlapping ethnographic projects. The first was an NSF funded project investigating design practices in both engineering education and workplaces called Cognitive Ethnographies of Engineering Design or CEED (Lauff et al., 2014). For this project, I, along with another research assistant on the project, observed three separate sections of a freshman engineering design, a year-long senior mechanical design course, department led instructor planning meetings for all sections of the freshman projects class, and senior design staff planning meetings led by the instructor of the senior project course. Observations were supplemented with ethnographic fieldnotes; classroom observations were video recorded, and planning meetings were audio recorded.

The CEED project specifically focused on the organizational features of design practices in undergraduate curriculum as design is widely taken to be the defining feature of engineering (Dym, et al. 2005). The project was structured such that disciplinary practices were to be observed in the classroom and by following one team from each course for the duration of their design project. Connections would be drawn between how design practices were enacted in the classroom and the ways they were organized and coordinated for by observing instructor and staff planning meetings. During my observations, I became aware of gendered practices and discourses that impacted the ways in which students engaged in design activities. This led me to develop a separate research project investigating the construction of gender in engineering. As part of that project, I sought out groups and activities related to engineering that specifically made gender salient including a women in engineering book club, meetings for the Society of Women Engineers, and a student group organized to support lesbian, gay, bisexual, transgender, queer, and ally (LGBTQA) engineers that I call GLE, Gay and Lesbian Leaders in Engineering.

My primary site of investigation became GLE. As my interest is in how students become engineers, I wanted to understand how the local meaning of actions, particularly classroom activities, were defined and interpreted from the students' points of view (Erickson, 1986). GLE was an intimate group of eight to ten regularly active members, and originated when a few students recognized the need for such a group locally. The small group format enabled me to be a participant observer in the club, affording me the opportunity to develop relationships with students and identify what this group of students themselves deemed important in the process of becoming of an engineer (Schenshul, Schensul & LeCompte, 1999). The students in GLE gave me insight into the lived spaces of engineering. In addition to attending weekly meetings that lasted one to two hours, I participated in organized social and networking events of the club, including an evening where the students spent the entire night in the engineering center, an easter egg hunt, recruitment trips to local engineering companies, and a conference on being openly "out" in engineering. During these events, I participated as a member of the club, and after the event I would write notes and memos about the events.

The data sources collected and reported here include multiple sites of observations that can be analytically categorized into the spatial trialectic framework. Spaces of practice include: where students engage with the disciplinary practices of engineering including buildings, classrooms, and laboratories; tools and materials students interact with; and the people that contribute to disciplining into the practice of engineering (Stevens & Hall, 1998). Spaces of coordination include where representations of engineering are developed, including the planning meetings as well as artifacts of engineering education such as journals and publication (e.g., the Journal of Engineering Education and the International Journal of Engineering Education, The Cambridge Handbook of Engineering Education.) The lived spaces of transformation include where students have moments of understanding as themselves becoming engineers and when they act according to that understanding.

My positionality as a researcher in this study varied by the sites I observed. During the senior design staff meetings, I sat at the table with the staff members and made notes about the conservation including expressions and reactions. To an outside observer, I looked like an administrative assistant intently listening to capture the meeting content but I rarely participated in the conversation. I waited until the end of the meeting to ask the senior design director any clarifying questions. During observations of the classrooms and student design team meetings, I regularly engaged in the conversations, asking questions regarding student decisions and processes. I participated as an active member of GLE, taking part in games, discussions, and events alongside the other members. Although I came in as a researcher and obtained informed consent from the students, over time I was recognized as member of the club. I was far from a distanced observer; I was more like a “passionate participant” (Guba & Lincoln, 1994, p. 115). For example, we discussed families, supportive siblings, and overbearing mothers. After I wrote observational notes, I would memo about my feelings in relation to the events in effort to document my self-awareness and affective reactions (Miles, Huberman, & Saldana, 2014).

Setting and Participants

This study took place at a research one university in the mountain west. The college of engineering enrolls almost 4,000 undergraduate students in eighteen different engineering and applied science majors, many of which are ranked in the top ten of the country. The participants included the students in the classrooms observed, the instructors and staff members who attended the planning meetings, and various members of engineering support staff that worked throughout the engineering center. The participants also included all active members of GLE. In addition to field notes, video recordings, and audio recordings of observations mentioned above, the data also includes nineteen qualitative interviews: twelve student interviews, and seven interviews from instructors, teaching assistants, and the director overseeing the freshman project classes. The interviews were conducted after observing the design courses and/or after months of completing participant observation in the GLE student group. The timing allowed for multiple perspectives and interpretation of the events observed (Weiss, 1994)

Approach to Analysis

The data was analyzed in multiple stages through constant comparative analysis (Strauss & Corbin, 1998). The project team met weekly to discuss emergent themes in the data developed through open coding and organized into broader categories through axial coding. Examples include: the idealized design loop, the space/location of design, and the development of relationships during design. As I collected data from the GLE group, I engaged in a similar process of identifying preliminary categories that were grouped into broader themes such as individual perspective of engineering, and significant relationships in engineering. Across all of the data I coded specifically for space and gender. I paid particular attention to data that referenced other spaces and places for example in analyzing a planning meeting I would code when a classroom practice was discussed or there was mention of how a particular event would be organized. Likewise, in interviews I coded when the respondent referred to disciplinary practices that shaped how they perceived themselves such as how they were expected to dress or act for a given event. As part of my analysis I wrote thick descriptions of engineering practices students engaged (Lincoln & Guba, 1985). To ensure the veracity of my descriptions, I presented them at a GLE weekly meeting and solicited feedback from the members. Similarly, I gave classroom descriptions to the instructors of the freshman design classes I observed for their feedback.

I am presenting my analysis as two case studies of individuals, Alex and Mary, negotiating their identities as burgeoning engineers. According to Yin (2009), a case study is the preferred research method when answering how questions and the focus is on a contemporary phenomenon within a real-life context. Thus, it is an appropriate method to answer the question: how do students become engineers? The case study method affords a rich description of events and individual perspectives from which we can measure our understanding of the phenomenon of engineering learning (Wolcott, 1990). It provides a way of both seeing and not-seeing the phenomenon thereby being instrumental in both examining and expanding our theoretical commitments (Stake, 1994)

I developed two cases in order to foreground how disciplinary practices are organized to recognize certain identity markers and not others. In particular, I chose to highlight how learning involves much more than accountable disciplinary knowledge (Stevens, et al., 2008) or the demonstration of competency in a given academic task. The students in both cases are academically successful; the epistemic demands of the discipline do not present a challenge to either of them. That being said, I wanted to be able to refer to the design experiences each student had as part of their curriculum in order to make connections to the classroom observations included in the data. It was important to me to have data for each case based on the student's own account of their experience as well as other participants' interpretation of these students' experiences: external interpretations both specific and general. Each of the two students discussed in the case studies were mentioned in other participant interviews specifically. For example, Mary's roommate, a member of GLE, was interviewed and during the interview she compared her own experience to Mary's. I drew on the data collected during the instructor planning meetings and senior design staff meetings to make connections between how the participants in these meetings constructed the generic student, and how this construction connected to the students' experience. For example, one topic of conversation in a planning meeting was regarding how men and women in the freshman project classes are expected to dress in professional settings. Although norms are determined for the generic 'he' or 'she', they directly affect individuals.

The cases juxtapose the experiences of a man and a woman. Although this is partly to demonstrate *how* particular sexed bodies are constructed in engineering, it is fundamentally to show *that* particular sexed bodies are constructed in engineering. How these cases differ analytically does not rest solely on the different genders of the students. In the first case, I demonstrate how Alex's gender and sexual orientation are produced in the multiple spaces of engineering. This case demonstrates the utility of the spatial trialectic framework in more fully understanding Alex's learning to be an engineer. Similarly, the second case illuminates how the spatial trialectic informs our conceptualization of Mary learning to be an engineer, but it also demonstrates Mary's deeply complex negotiation of identity as an engineer beyond her gender and sexuality. What differentiates the two cases is not the degree to which each student is produced in engineering, but the extent to which the spaces of engineering limit the possibilities of who you can become as an engineer. Before presenting each case, I introduce the spaces of engineering common to both.

Limitations

A primary limitation of this study is that I was the sole researcher connecting the multiple spaces of engineering. As with any interpretive research, a risk is present that I missed a particular insight or framing that could fundamentally shift the interpretation of events (Erickson, 1986). I mitigated these risks by sharing my description and analysis with the study participants. In particular, my analysis has been shared with members of GLE multiple times, and their insight and questions allowed me to refine my understanding of learning to become an engineer.

THE SPATIAL PRODUCTION OF LEARNING TO BECOME AN ENGINEER

My research documents the spatial production of students becoming engineers. A process of becoming suggests a *telos*, or an end point for what these processes will accomplish. In the case of learning to become an engineer, the *telos* is a professional engineer. My analysis does not attempt to capture the degree to which these processes emulate the actuality of engineering professionals nor how many students do in fact become professional engineers. My analysis, rather, examines the ways in which the concept of professional engineering is present in the spaces students interact while learning to become an engineer. For this reason, I examine how spaces of practice emulate professional engineering, how spaces of coordination are organized to promote professional engineering, and how spaces of transformation reimagine professional engineering. I describe each spatial axis before presenting my case studies of student becoming engineers.

Spaces of Engineering Practice

Spaces of practice encompass the perceived experience of those engaged in the practice under investigation. My work is focused on students. Much of students' time is spent in the classroom. The coursework that I observed focused on instructing students in design. As part of this instruction students were introduced to and/or expected to reenact the design loop. The design loop is thought to guide students through one process that professional engineers engage in order to find the solution to an engineering problem. The design loop is an iterative process that begins with identifying a problem, brainstorming solutions, evaluating constraints, prototyping one solution, and then iterating on this process to develop the best possible solution to the original problem. In addition to learning the parts of the design loop, students engage in other activities similar to professional engineers including working on teams and group presentations. Furthermore, they are instructed on how to present themselves professionally including how to dress like a professional, create resumes and portfolios of work, and prepare for job interviews. For example, the freshman team I followed as they designed interactive electronic devices not only experienced the design loop when they created their final projects, there were multiple experiences of working as a team in different places and with different people including the electronics and laser cutter labs, presenting their initial design to both their classmates and appointed design experts such as the director of manufacturing, and presenting their final product to the client and in a final campus design expo. These experiences were intended to enable students to act in the manner of and produce artifacts in accordance with what is taken to be professional engineering.

Spaces of Engineering Coordination

As students are engaging in spaces of practice, these same spaces can be understood as spaces of coordination. Individual students experience the practice, while instructors, planners, and engineering education researchers devise and plan for student experiences. Spaces of coordination are the conceived representations of space. In the case of undergraduate design curriculum, instructors and planners are creating spaces that they believe will support students in understanding what it means to be an engineer. For example, Sonja, the instructor of the freshmen projects class building a playhouse, organized her class so that students had a client as professional designers would. Not all freshman projects classes have clients because instructors are able to organize their courses to emphasize the features they think are most salient in learning to become an engineer. Coordinated spaces reflect the interpretations of the organizers. For example both of the instructors, Michelle and John, maintain that in order to become an engineer one must possess capacities beyond skills, and that the skills themselves are secondary to being an engineer. As they explained:

> "The building part is skills, you get that along the way, I mean it's - it's skills. There are thousands and thousands and thousands of people that have skills, nobody hires you anymore on your skills, um, you can spend a whole lot less than get a highly educated skills person, people hire to problem solve, my view point is you first learn how to problem solve and then learn skills, skills come as part of it." (John, instructor freshman projects)

> "We are trying to say Engineering is not, is not Dilbert, it's not the cubicle in the corner where you go to crunch numbers, we got computers for that…It's being collaborative, being creative, and being problem-solvers, and resolving issues in a manner in which nobody else has ever thought of before." (Michelle, instructor freshman projects)

Michelle and John both articulate that problem solving is part of the design process and is expected of professional engineers. Notice the difference in how engineers are positioned by each instructor. Michelle, unlike John, emphasizes creativity and collaboration in addition to problem solving, John argues that problem solving is fundamental. One of the purposes of capturing the spaces of coordination is to highlight the ways in which particular concepts (i.e., problem solving or creativity) become more consequential than others (i.e., skill building.)

Spaces of Engineering Transformation

Engineers-in-the-making engage in practices that are coordinated by others in order to become a future self. They are more than reflections of practice and coordination, they are agentive selves that do and do not take up the practices and intentions put before them. The third trialectic of space captures the interaction between lived experience and ideology, and represents the opportunity for symbolic possibility. It is in this space that transformation is enabled.

Engineering students are presented with different possibilities of being in professional engineering. These possibilities can either be constraining or liberating. As students progress in their academic careers, they are encouraged to join professional organizations, intern with prospective employers, and generally understand their employment possibilities. In these ways, the engineering students experience various professional engineering practices and become symbolic representations of their future selves. Consider this example: students in GLE were invited to tour the aerospace engineering company Lockheed Martin as part of a GLBTQ recruiting event put on by the internationally known company. One of the tour guides appeared to have very masculine physical features but was wearing very feminine clothes including a flowery blouse, my assumption was that she was transsexual; the other tour guide wore various symbols of gay pride including a rainbow on his identification badge. Students were led through secure areas to see space shuttles in the making, engineers working on designs, and computer monitoring stations that track all aircraft in the earth's orbit. In each of the different parts of the tour, the other employees welcomed the tour guides warmly. The company represented itself as a space that welcomed GLBTQ engineers. This welcoming space is not always present in professional engineering organizations. As Natalia, a GLE student, told me, she used to attend professional events hosted by the Society of Women Engineers (SWE) but she stopped because too often the organizers discussed the importance of balancing work and motherhood. Natalia said she had no intention of being a mother and found SWE events to be too heternormative in regards to assuming all women identify with particular sexed and gendered roles based on their biology (Warner, 1991). The events at the engineering company and SWE highlight the ways in which students are positioned to imagine their futures selves as engineers.

I argue that to fully appreciate the phenomena of how professional engineering is manifest for undergraduate engineering students, all three spaces must be considered. The *practice* captures the activities student engage in, the *coordination* captures the intention behind these practices, and the *transformation* describes how both are taken up or not for students. The cases I present articulate the limits and possibilities each student imagines for him or herself as a future engineer, and the spaces that afford and constrain this imagination. In the first case, Alex is limited only by his sexual identity, which he has a plan to navigate when entering the engineering profession. Mary, on the other hand, has a more disparate understanding of how she sees herself an engineer.

A CASE OF SPATIAL COHERENCE: "I CAN GO WHEREVER I WANT"

When I asked Alex, a sophomore in Chemical Engineering and Applied Math, why he chose engineering, he responded, "I chose engineering because I could take the skills and the practices I use in my degree—in my engineering degree—to pretty much go wherever I wanted to." Alex hopes to work in the field of renewable energy in the future and he is confident about this future. Alex's understanding of himself as an engineer is being constructed in both his classroom experiences and his experiences as the GLE vice-president. Before I document how GLE provided moments of transformation not always present in classroom, I detail the spatial practices Alex experienced as a student and their coordination. I begin by describing Alex's experience with freshman projects. Freshmen projects, as explained above, is one of spaces of practice designed to expose students to professional engineering. It is also a highly coordinated space.

Alex's freshman projects class was organized comparatively to the freshman projects class I observed of students building a playhouse for physically disabled child and his able-bodied younger brother. It was similar in that Alex's instructor sought out opportunities for her students to design a product for an actual as opposed to hypothetical client. For several years, Alex's instructor worked with an organization that provided assistive technology for disabled individuals. Alex's team, composed of two women and two men, developed a mood lighting lamp activated by slight touch for a wheelchair bound man with limited hand mobility. Alex described the instructor and class as follows:

> She works with a company called (name) that works on providing developmentally disabled people with assisted (sic) technology. That was the slant of that whole class. Because the topics and the projects were largely up to the choice of the professor. Because we had Professor (x) she was like, "Okay, you're gonna actually get a client. You're gonna design something. By the end of the semester you're gonna have a deliverable, and you're gonna give it to them."

By all accounts, and to use his words, Alex's freshmen projects class was "a success." His team won best in section; his client seemed to like the design. Alex and his team proceeded through the design loop and in doing so Alex said he learned to "cooperate and collaborate" with his team. When I asked what he remembered most about the class he said:

> Having to work with a team…There's that process of getting to know them more personally and figuring out what their work styles are and what they are good at and what they wanna do and to allocate all of your talents in such a way that is most efficient and makes the best product. Granted none of us really had any of the skills, so that was—so it mostly boiled down to what do you find interesting, what do you wanna get more involved in within the project to promote interest.

The freshmen projects class exposed Alex to the practices of engineering that instructors intended and for which they purposely organized. Alex commented on the "process of getting to know" other students and working with them. Teamwork and working with others is planned for in the classroom to prepare students for their future as engineers. Take for example a freshman projects instructor who said:

> We're asking students to be able to interact, and collaborate, and not with just the same people you're used to…people from different cultures… people who have had struggles…and not everybody is cool with that yet. 'I just want to be, you know, the technical piece'…and that's not enough. We're hearing that from companies, we're hearing that from society.

The instructor emphasizes that companies are looking for collaboration not just the technical piece; Alex said, "none of us really had any skills" and yet they won best in section. It is important to note that despite Alex and his team not having the skills, they acquired the skills through the duration of their project. Part of the spatial practice is the experience of going to the electronic shop, learning the skills necessary to create the end product, and developing relationships. This should not be overlooked as it connects students to the socio-technical system of engineering (Weidler-Lewis & Lauff, in preparation). The class that Alex took had a team of researchers informing instructors on how to make sure students are exposed to skills at the same time that they are learning "teamwork, collaboration, and cooperation."

Alex had fond memories of his class stating, "I enjoyed it a lot. I mean, I learned a lot." By suggesting how much he learned, Alex was revealing his understanding of what it means to be an engineer. He was able to connect his understanding, with his affective response of 'enjoyment' and what actions he took as an engineer. He further described the class as, "there was actually an objective, and you fulfilled that objective. You actually did something good with what you did. It wasn't just like, 'design this. Oh, it's never gonna be used again. Now we're gonna take it apart and throw it away.'" His freshman project class positioned him as a capable engineer that "actually" makes a product to do "good" in the world.

Alex also recognized that different instructors prioritize different aspects of the class and that projects were "up to the choice of the professor." Alex, however, is unaware the extent to which the practices he engaged are the subject of study, coordination, and debate in the field of engineering education. While Alex felt successful, a different freshman projects instructor, John, had disdain for the class Alex took and when asked about it, replied:

> …design isn't something you can teach in one hour blocks once a week…you've got to understand how to develop - to look at theories of design - there are so many things that come in - it is not just - come up with a concept, test it out, prototype it, test it, refine it, do it again. That's shop class.

John refers to Alex's class as "shop class" in reference to the fact that Alex's class was organized to privilege technical, construction skills rather than less tangible skills like design thinking and problem-solving skills. Similarly, a different instructor called Alex's class "arts and crafts" to emphasize how practical skills were seen as immature compared to more demanding theory-based skills. John's philosophy of design is different than other instructors of freshman projects, and this impacted the organization and coordination of the way John teaches his class (Weidler-Lewis & Lauff, in preparation).

Other consequences are made evident when spaces of coordination are examined, consequences about which Alex is never made aware. For example, Alex said that his team was composed of two women and two men and that he did not have the choice of his teammates. Team formation is a much-researched topic in engineering education. The instructors for freshmen projects are strongly encouraged to pair women on teams and base this recommendation in research on persistence of women in engineering (Tonso, 1996). Another consequence that Alex would never be made aware of is that in the instructor meetings for freshmen projects, instructors debate the proper way to address students in class. In one meeting instructors agree that male students should be called “sir” while they remain undecided if female students should be called “ms.”, “miss” or “madam”.

The instructor meetings are a space of coordination for the classrooms. Discussions in these meeting are routinely about how to organize the classroom to be like professional engineering practice. The conversations range from how to instill time management in student to how to students should be expected to present professional posters because this is a “professional skill.” In the final instructor meeting of the semester, instructors discussed how student should dress for the design expo. The program director began by saying, “for males this means business casual, khaki pants and a button down shirt, khaki pants and a polo shirt, khaki pants and collared shirt.” As a space of coordination, instructor meetings represent how the norms of engineering are decided and enacted in the classroom and become more than simply one instructor’s decision on how to teach a class.

As a white male in engineering, many of the coordinated practices, such as 'males wear khaki pants and a button down shirt' do not conflict with how Alex sees himself. As a gay man, however, Alex, is reflective about whom he can be as a future engineer. Alex wants to "bring his whole self" and not hide who he is and wants to be. He is conscientious about the organizations and relationships he pursues; he actively researched campus groups to become a part of when he started college. When he discovered GLE:

> It was like, oh, it's a group of LGBT engineers. I'm like, 'that might be refreshing to see other gay engineers.' Cause I had heard that engineering is, again, kinda homogenous white male – white straight male. I was like, "No, I wanna meet people who maybe aren't in one of those categories.

During his freshman year, he participated in GLE activities and made the decision to run for a club officer by the end of the year. GLE enabled Alex to envision who his future self could be as a gay man in engineering. Alex organized activities that encouraged a vision in which being gay is congruent with being a professional engineer. For example, Alex organized for members of GLE to attend an oSTEM (out in Science, Technology, Engineering and Mathematics) event hosted by Google. GLE represents a space of transformation. It is space where students can contest the practices and coordination they encounter becoming engineers and imagine who they want to become. In addition to envisioning this future, GLE provides actionable steps to make this happen. For example, Alex learned at oSTEM that he wants to put his work with GLE prominent on his resume. His reasoning is that homophobic organizations will likely pass him over and he'd rather work for a company that supports who he is:

> That was one of the biggest workshops takeaways - is that don't hide it. If you hide it while you're applying for a job or you're in the workplace or something like that, you're not bringing your whole self to the table, because you'd perhaps be hiding skills that are related to your LGBTQ-plus identity. That really resonated with me, so I just don't hide it anymore. Plain and simple, I don't care what anybody thinks. If somebody is going to remove an opportunity from me because I'm gay, okay, fine, I didn't want that opportunity anyway.

Although Alex recognizes that some institutions are unlikely to change, he values diversity in engineering, "I feel like if people from different backgrounds can work together and just be around each other, it makes for a more interesting, more diverse cultural landscape and just overall viewpoint." He would also like to see GLE expand, "having GLE have a large presence here in the engineering centers promotes diversity and shows –a- we're not so homogenous…or here we're queer, come hang out."

I cannot say with certainty that Alex will transform professional engineering practice, but he has a vision for how he could be accepted in a practice that at one time may not have been so inclusive. As researcher of learning, I argue that the spatial trialectic gives us insight to ways in which we can think about and organize for learning. The spaces of the trialectic are not meant to be seen as isolated categories; they are intertwined and reflexive, but they do reflect analytic categories that can be meaningful in understanding the complex processes of learning within a given practice. Again, to fully recognize how Alex is learning to become an engineer, all three spaces must be considered: practice, coordination, and transformation.

A CASE OF SPATIAL DISJUNCTION: "WHEN IT COMES DOWN TO IT, I'LL TAKE ANYTHING"

Mary, who was entering her senior year in Aerospace Engineering, was beginning to focus on finding a job after graduation. Her dream job would be to work on aircraft for Boeing, the world's largest aerospace company; however, she had already applied to sixty different internship sites for the summer and had not heard back late into the spring, so after graduation she was willing to work at "any" engineering aerospace related job. She decided to become an engineer after seeing a presentation in early high school on NASA and the International Space Station which she thought was the "coolest thing." She has never wavered from pursuing aerospace, but what that will ultimately entail is unclear. Much like the uncertainty of where she would find a job, Mary's vision of who she is, and will become, is disjointed, and this is reflected in a spatial analysis of her experience.

Mary does not lack ability or confidence. As an aerospace major, she knows that everyone in her major is academically sophisticated and capable, or as she recognizes, "we've all graduated top of our class, otherwise we weren't in this program." Engineering in general, and aerospace in particular, is perceived as both challenging and competitive. For example, the fact that she had applied to sixty internships was not uncommon; when I inquired if she really said sixty, she responded:

> Yeah, but apparently that's how it's supposed to be. My friend applied at 67; didn't hear back from any of them except for one and that one person offered him an interview opportunity and he got hired. You have to try in a lot of places. I've tried in a lot of places.

Engineering is organized to be competitive. During one instructor planning meeting, the instructors discussed how students at particular urban high schools could get perfect class scores at grade level but "there is no chance of them being admitted into the college of engineering" because in order to be admitted to the program you have to perform better than grade level at math.

Mary's cohort started with 120 members. After the third year, that number was down to 80. Aerospace classes are notoriously difficult. In addition to the demanding content, many of the classes have strict curving practices in which a particular percentage of the class fails simply by scoring in the lowest percentile in the class, regardless of total score. There is no shame, however, in failing a class:

> Yeah. I actually know—a lot of my friends who've failed a class are here again so they're a year behind me now, but they're still going for it. If you fail early enough—this is weird to say—but if you fail early enough, you can add a minor 'cause you have that extra year of classes that you can just, if you wanna do, you can just take minors.

Students are expected to work hard and it is not uncommon to find students at the engineering center working until one o'clock in the morning. Mary tells me she can always find the "aero kids" when she needs them. Students are also expected to become specialized and this is mirrored in how professors approach their work:

> I mean I think that all my professors are quite impressive in what they've done. They've all done different kinds of research, so I think it's different—I guess what you're interested in. Sometimes it's really impressive that they know so much, but if you think

> about it in the grand scheme of things, they really don't know that much. They only know that much about one tiny, tiny aspect of engineering. One of my teachers is really, really smart, works with airflows and that's it. Airflows is the shape design of the wing of an airplane. That's all she does. She did that for like 15 years and she knows all about it, but does she know about anything else about the airplane? Probably not.

Mary perceives engineering as isolated both in its content and physical location. The engineering center is located on one end of the campus, while many of the arts and sciences buildings are on the other side of campus. Engineering students are not expected to take classes outside of their discipline except perhaps Humanities for Engineers. Engineering students do not regularly interact with other majors. The differences in the disciplines are apparent for Mary even in how students dress and act:

> I think that's (not interacting with other majors) been developed because we've been so isolated, almost from the rest of them that we don't understand them. Sometimes I also think that if you walk from here to the (other side of campus), the way people dress and carry themselves at the (other side of campus) are very different from the ones who dress and carry themselves here. I kinda wish it was more integrated, like it was more like the same thing, but I feel like it's not because we just don't interact with them at all, pretty much. That's what I would like to see change. That's not gonna happen.

Mary's perception of engineering practice reflects the dichotomous quality of the discipline. Everyone in her field is academically intelligent; in order to be accepted into and continue on in the program you must perform exceptionally well. Professors become highly specialized, which Mary says represents “knowing so much” and yet because they have become so specialized the do not know about anything else, including how to communicate and interact with other people in other disciplines. For Mary, the “ideal engineer”, if there is one, is someone who can balance both discipline specific demands and living in a broader, social world. In this way, Mary perceives engineering as a practice that unduly ignores “social life” and “social skills” in favor of specializing in “one tiny aspect” of an engineering skill.

Although the designers of the engineering center are unlikely to describe it as “isolated” from other parts of the campus, the building was intentionally created to provide for engineering students’ needs and allow them to “claim” the space and make it their own. For example, students in the freshman projects class are assigned lockers for their projects that become “theirs” for the semester. The building has multiple, reservable study rooms for student use only. The “aero kids” study in a specific lab with computers that have software specific to their projects. Students did not merely adopt these places, they were designed for by the engineering education staff according to what they believed would benefit engineering students. Multiple features were built into the engineering center to reinforce engineering principles. For example, a wall was purposefully left exposed in order to show the material support, circuitry, and ventilation of the building.

The design of the space is to inculcate engineering students into the professional practices of engineering. This includes having students present their designs in a professional manner; I discussed the freshman project expo as one example above. The ways in which events are coordinated, define the ways in which students are expected to perform; this means something very specific for Mary, and all women. Recall that the program director told instructors to advise their students to dress appropriate which for "males" meant khakis and a shirt but when it came to women, he said, "for females I'm not exactly clear on what that means. The discussion continued on with one female instructor saying, "I know what it doesn't mean. It means don't wear party clothes, it's not party clothes." After the director suggested that using the expression "dress conservatively" usually conveys the right message, the female instructor continues, "dressing up for young women can be some pretty hot, short, high-heeled party clothes. The language is important, conservative business dress." A discussion regarding dress ensued with the director and two instructors:

> Director: And they will need to wear nametags and my rule of thumb with nametags is if you don't have a place for putting your nametag then you don't have enough fabric on your clothes,
>
> Female Instructor 1: I Often have women putting their name tag down here, and I'll go up to the women and ask why would you like someone looking at that part of your body. You probably get enough of those observations.

As the conversation continues, the second female instructor says that the students are representing the university and if they do not dress appropriately, they should be sent home.

> Female Instructor 2: Go home, you didn't show up how you were supposed to. I'm done! Skirts need to be right at the knee, don't wear high heels you can't stand three hours in. It's not that hard. I'm a perfect example of how to dress appropriately, I don't show up in skirts and high heels, I don't understand why it is so hard. They don't understand, I'm a little frustrated with the whole thing because I'm a female, so it makes me crazy.
>
> Female Instructor 1: So is it particularly with women that you have issues?
>
> Female Instructor 2: Well a couple of my guys showed up in tennis shoes and baggy shirts and I find that not appropriate either, so I also said that, but I find, but I find that not revealing or not sexualizing a male, I just find you look sloppy so it's different for me.

In this space where instructors come together and discuss the "appropriate" dress for men and women at the engineering expo, they are directing and organizing how students are supposed to act as "professional" engineers." Based on this discussion the expectations for men and women are "different". Women's attire is much more regulated due to the fact that women are "sexualized" and have "parts of their bodies looked at." Furthermore, women are supposed to model themselves after the more experienced, "perfect example of how to dress appropriately." In this way, 'professional female engineer' becomes defined and measurable by the standards set and modeled among the instructors. The challenge for Mary is that this is both an abstract and false measure for her. As she would say about her appearance, "I'm awkwardly in the middle. I have tendencies to be like super guy. (Her girlfriend) has told me this several times: if I put on some girl clothes instead of baggy pants and a baggy T-shirt, I look like a girl." The measure of professional attire is easily identifiable for a man, "khaki pants and a buttoned shirt." For a woman, it means do not "sexualize" yourself while you wear a knee-length skirt, but otherwise it is unclear.

As Mary makes sense of herself in relation to her perceptions and the expectations of disciplinary practices, it becomes apparent that her lived experience involves bridging multiple aspects of her identity. Mary is an Asian, lesbian, Christian woman in engineering. Parts of her identity are made more salient depending on the situation, but the complexity of her experience is always present. For example, she believes being a woman and Asian will help her find a job, even though it often times "sucks" being a woman in applying for jobs in a male dominated field. After I asked her, why does it "suck" that engineering is dominated by men, she responded:

> I don't know. Sometimes they think they're better than you, they're smarter than you just cause you're a girl and I'm like, "That's not true." It's kinda nice, though, cause then if they have a good HR department and they want diversity, I have more of a chance to get in cause I'm a woman and a minority.

Mary recognizes that companies will often hire for diversity, but she also realizes that being Asian is not always considered minority status in engineering. Engineering education routinely distinguishes between White, Foreign National, Asian-American, and URM in relation to diversity (e.g., Chubin, May, & Babco, 2005). An 'URM' refers to an under-represented minority. Mary does not fall in this category and recognizes that she does not benefit from many programs targeting 'minorities' in engineering. Mary's roommate believes that Mary is no different from other minorities, "My roommate, tries to think that that's not true. She thinks I have all the benefits and I'm like, "No, not as an Asian in engineering. There's a lot of us."

Engineering educators define categories of minority from which they can then measure the diversity of field. Conversations of diversity are present in spaces of coordination. During an instructor meeting regarding how to increase participation in the field, one instructor discussed how toys such as Goldieblox are targeting young girls in their marketing. She continued to relay how her daughters benefited from these toys and other "fun" engineering projects like complicated rube-goldberg machines. She connected this experience to the freshman project expo and how exposing middle and high school students to the "fun" projects at the expo can spur interest in pursuing engineering, and that is why they are promoting the expo to area schools. Another instructor asked the group, "Are we making special outreach programs to students of color?" She continued, "you say, 'I do all this stuff with my children,' I'm not worried about your children, I am not worried about your children making it to college. I am worried about the kids that are out in the world." Through this conversation 'students of color' became a category that could be organized for in designing the engineering project expo. It was not a category, however, that Mary neatly fit.

Mary did fit into the category of woman. Engineering as a discipline is known for its underrepresentation of women and the various problems women face because of this and Mary has not escaped these challenges. How lesbian women navigate these challenges, however, often depends on how "women's issues" are defined heteronormatively (Weidler-Lewis, in preparation). Mary is gay, Christian, and Asian;

she "struggles" to make sense of this.

> I have never tried hiding being a Christian. I've definitely struggled with the fact that I'm gay and Christian. The two things didn't mix well. I didn't know what gay was till I was 16 years old anyway, but it wasn't till college till I realized that I probably was. Then it was kind of like, "But I've grown up 19 years of my life learning that this is wrong." In the Christian community, I do not openly say that I am, just in case.

She has tried to find a space that could enable her to be forthcoming with multiple aspects of her identity. When she began school she joined an Asian, non-denominational Christian group. She left this group because despite claiming to welcome diversity, the group only tried to recruit other Asians. She was part of an off-campus gay Christian group, but she enjoyed GLE and the meetings conflicted. She knew of six students in aerospace that formed a bible study but she was not sure if she "wanted to spend any more time with the aero kids, than I already do." Nevertheless she said, "I do want to find a group again," referring to a group that studied the bible and welcomed diversity. Although GLE is welcoming of diversity, it is unlikely to be a space where Mary would practice her religious views, which she "will never hide."

Mary's moments of lived space are discordant regarding features of her identity because of how situations are perceived and conceived. She is either a lesbian engineer in GLE, an Asian female in engineering, or a Christian Asian in engineering. She has yet to find the one place where the disparate aspects of her identity coalesce, and she may never. However, this does not mean that her experiences do not inform our understanding of her learning to become an engineer. Mary helps to reveal the true complexity of creating a new way of being in the world and negotiating a new identity. Examining all of the spaces of a discipline reveals what gets defined and organized for and what does not.

DISCUSSION

Using a spatial trialectic framework as a method for studying and analyzing learning reveals the complicated processes of learning within a discipline. In my analysis of two students becoming engineers, I identified how the practices of engineering are perceived as a discipline, organized and coordinated to make certain identities salient, and the moments when students envision themselves as engineers. By articulating the trialectic as distinct, yet intertwined axes of learning, each can be identified as a particular process to be interrogated for its "relations of power" that dictate behaving, thinking, and acting (Foucault, 1976). However, each is reflexive of the other, and it should not be forgotten that any space is simultaneously perceived, conceived, and lived.

The engineering practices I reported on represent a moment in the history of how undergraduate engineering education is performed; it has changed and will change. As mentioned above, design is considered the defining feature of engineering (Dym, et al. 2005), and yet what are the pertinent features of design and how should we coordinate for teaching design is contested (Weidler-Lewis & Lauff, in preparation). Studying spaces of practice via the students that live these spaces shows the ways in which the practices both support positive and negative consequences of the discipline. For Alex, engineering was a way to do "good" in the world. For both, engineering suffered from a lack of diversity of students that did not represent the world they wanted to live in. Relatedly, Mary's experience showed the challenges of being a woman in aerospace are not related to her ability to perform academically.

Studying spaces of coordination established connections between those who had the power to coordinate engineering, like the instructors and directors, and the students who are becoming engineers. The spaces of coordination define what are and what are not appropriate representations and measures of engineering practice. The focus of the two cases did not consider how the instructor planning meetings were also lived spaces of transformation, but it is clear that the people in these space envision what engineering can be as well as define what it is. When the instructor asked, “are we making special outreach programs to students of color?” she was drawing on her lived experience as a Hispanic engineer. She produced a moment of opportunity for transformation of the practice.

All spaces are lived spaces and, thus, have the potential to lead to transformation. Studying the student group GLE as representative of a transformative space for engineering uncovers how moments of understanding lead to pathways for change. GLE could be examined as, and is, a space of coordination for its members. They produce representations of what it means to be LGBTQ engineers, and they plan for activities to support these representations. However, if GLE had been the only space of study, much of the power of the disciplinary practice would be overlooked.

CONCLUSION

Jean Lave argued that learning is a process of “changing participation in changing communities of practice” (1996, p. 150). What the spatial trialect approach to studying learning affords is that this one unified process we call learning can be examined by a multiplicity of processes in order to keep together our awareness of disciplinary practices, our desire for equity, and our capacity for transformation. The spatial trialectic provides both a theory and a method for our inquiry into learning. As a theory, it provides a framework for developing connections between how learning is organized, for what purpose, and with what consequences. As a method, it guides decisions and procedures for how we investigate a given phenomenon of learning. Although it provides direction for study, it is not rigidly prescriptive, and can be used at various scales from entire disciplines to isolated events.

As researchers of and designers for learning, Learning Scientists should be mindful of the representations that we produce. We do not stand apart from our research, and should be subject to the same scrutiny I have given spaces of coordination. As we continue to seek explanations of and organize for learning, we should challenge ourselves to create moments of potential transformation that can lead to more just and equitable outcomes.

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CHAPTER FOUR

Transformation and Stasis:

LGBTQA Students' Prefigurative World of Engineering

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Abstract:

The underrepresentation of women in Science, Technology, Engineering, and Math disciplines continues to be researched and programs are continually developed to address the dearth of women in STEM. Educators have called for this phenomenon to be studied from an intersectional approach, which includes sexual identity. This article examines how a group of students interpret their ability to transform the field of engineering to be more inclusive. Drawing on interviews from eight LGBTQA undergraduate students in the process of becoming engineers, I show how these students draw on engineering concepts to both reimagine and reorganize engineering to be a more inclusive environment for sexual orientation. Although challenges persist for women, I argue these students create new possibilities for equity in engineering by enacting prefigurative worlds.

Introduction

Despite decades of research, as well as programmatic efforts to change, underrepresentation of women in STEM disciplines persists (Hill, Corbett, & Rose, 2010; NCWIT, 2014). The problem of underrepresentation has been so persistent for so long numerous attempts have been made to synthesize all the research to date and possible solutions (e.g., Kanny, Sax, & Riggers-Piehl, 2014; Corbett & Hill, 2015). This has not prevented the call from industry, presidential commissions, and other organizations to increase participation of women in the field (NRC, 2011; The White House 2009; NCWIT, 2015). With the underrepresentation of women as an impetus for investigating disciplinary change, this article examines the connections between the construction of gender and sexuality in engineering with efforts to organize social change in a discipline.

As part of a larger ethnographic study examining how undergraduate engineering education organizes for design in the classroom, I observed two semester-length freshman engineering design courses, and a yearlong senior mechanical engineering capstone course. During my observations I noticed the ways in which women, men, and gender ambiguous individuals were treated during routine classroom activities. The students who did not perform as either male or female were often expected to conform to a particular gender norm by, for example, adhering to dress codes or assuming certain roles on project teams. Although I witnessed these events unfold, I rarely had a chance to ask the students about their experiences. I wanted to know if the students themselves observed or experienced the same phenomena, and if so, how were they affected? Did it change their perceptions of themselves as burgeoning engineers? In an effort to understand students' undergraduate experiences in engineering more fully, I began attending weekly meetings for a student group of lesbian, gay, bisexual, transgender, queer, and ally (LGBTQA)[1] engineers that I call GLE, Gay and Lesbian Leaders in Engineering.[2] I interviewed eight students from the group and here I present the findings from these interviews. The interviews show how these students individually and collectively constructed meaning related to gender and sexuality in engineering by contesting the definitions available to them. The representations of engineering do not often validate the intersectional experience of being LGBTQ in engineering. The students, therefore, actively worked to transform engineering to recognize the new meanings they created for themselves.

Embedded in their actions is a different way of being that imagines how the world could be constituted differently and thereby makes this difference a real possibility (Levitas, 2013). How these students were making disciplinary transformation possible should interest researchers who support creating more gender inclusive disciplines. This research continues work that examines learning and becoming through collective organizing (Shea, under review) as well as the call for educators to "consciously organize opportunities for students to analyze and work to transform the social problems that directly affect their everyday lives" (Vossoughi, 2014). In this way, the research presented here is an analysis to show the "prefigurative" lives of students insofar as documenting how they organize in the present in ways consistent with their future goals, and in doing so create this future.

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[1] I use LGBTQA rather than other acronyms that include asexuality or intersex for example LGBTQIAA+ because the students I studied used the LGBTQA acronym. It is important to note that research is not consistent in how disparate identities (e.g., lesbian, gay, bisexual, transgender, queer) are formed into a common whole.

[2] All names are pseudonyms.

The students I interviewed shared a similar perspective of what it means to be an engineer, one in which engineers engage in problem solving to change the world. They recognize how local engineering challenges relate to global phenomena, and how working on local change can lead to global change. Similarly, they demonstrate how students willing to change their proximal experience of learning to be an engineer, by this I mean what is happening at their campus and in their immediate lives, can have lasting effects for the discipline of engineering.

I begin with a theoretical framing of gender, sexuality, and heteronormativity. In this section, I define the concepts used throughout the article. Next, I examine the research investigating gender and sexuality in engineering. This is followed by my research design and why an interview study is the appropriate method for detailing the meaning students give to their experiences. In my analysis I show how these students are defined by more than their gender and sexuality alone. However, all women, regardless of sexual orientation, experience effects of their gender in relation to engineering. As students grapple with and contest definitions of gender and sexuality, they create new ways of participating in engineering opening new possibilities for understanding gender and sexuality in the field.

Gender, Sexuality, and Heteronormativity

In this study I use concepts of gender, sexual identity, and heteronormativity to analyze the experiences of the students I interviewed. I am limiting myself to these three concepts knowing that our sexed and gendered lives are more complicated to include categories of sex, gender, gender identity, gender expression, and sexual identity, and that our lives do not always fit into the rigid binaristic definitions these categories often assume. However, this research attempts to understand how particular bodies become underrepresented compared to other particular bodies. For this reason, I subsume sex and gender related categories under the term gender to refer to the fact that female bodies (women who are either masculine or feminine) are underrepresented in engineering

I agree with Butler (1996) who differentiates biological sex (male, female) from gender (masculine, feminine), and that our knowledge of both is produced through discourse. Gender is a performance that constructs the social order of what is thought to be “normal.” Butler argues that there is a tendency to see biological sex (male, female) as causing gender (masculine, feminine), which in turn causes sexual desire (homosexual, heterosexual). This view, however, is part of hegemonic structure of sexuality that forces categorization into oppositional binaries of male/female and masculine/feminine. I draw on Butler’s ideas to reaffirm that both women and men can present as masculine and feminine but because engineering is “marked” as male, women are seen as not belonging regardless of their gender expression (Faulkner, 2009).

Much like men and women are expected to perform as masculine and feminine, there is an assumption towards “compulsory heterosexuality” or the belief that women and men are ‘naturally’ attracted to the opposite sex (Rich, 1986). This results in heteronormativity, in which norms and practices associated with heterosexual bodies are ‘naturalized’ but always in relation to nonnormative genders and sexualities (Warner, 1991). Heteronormativity is the expectation that all women and men identify with particular sexed and gendered roles based on their biology.

Literature Review

Although there have been calls in the research literature on issues of inclusion in STEM fields to investigate women's learning from an intersectional framework, a framework which includes sexual identity (Bruning, Bystydzienski, & Eisenhart, 2015), the research is scant. In a 2011 article, Cech and Waidzunas presented research findings from interviews and focus groups of 17 gay, lesbian, and bisexual engineers. Their results showed that engineering education was a hostile environment for students who often tried to "pass" as heterosexual. Since then only one other study has examined LGBTQ students' experiences in engineering. An interview study of 16 undergraduate engineers who identified as lesbian, gay, bisexual, or transgender also reported LGBTQ students face heteronormativity and exclusion in engineering practice (Trenshaw, et al., 2013). This study also reported that LGBTQ engineering students felt left out of the larger campus organizations supporting LGBTQ issues.

Most research analyzing sexual identity in relation to STEM disciplines is focused on workplaces. Like the two studies above, this research is also focused on perceived climate of organizations. Hostile academic climates have been reported for faculty in Science and Engineering disciplines (Bilimoria & Stewart, 2009). Similarly, Patridge, Barthelemy & Rankin, (2014) analyzed factors related to academic climate and LGBQ[3] faculty career consequences. Riley (2008) reported that engineering workplace culture can undermine efforts supporting LGBT-friendly policies. A 2016 study by Yoder and Mattheis surveyed over 1400 LGBTQA workers in STEM careers and found that employers with more representations of women were reported as having a higher degree

[3] As mentioned previously, there is no consensus on the research regarding what identities are included. For example, this particular research did not include transsexuals.

of openness to LGBTQA individuals, and those reporting a higher degree of openness increased the likelihood of describing their workplace as safe and welcoming.

The dearth of research on the relationship between gender and sexuality in STEM disciplines suggests that much is to be gained from analyzing how students make these categories meaningful. Although most of the research focuses on “chilly” climates for LGBTQA engineers, the students in this study were part of a positive climate for LGBTQA engineers, and yet the women still experienced gender based discrimination in classrooms and workplaces. Rather than focus on the perceived climate of engineering, my focus is on the individual and collective organizing these students engage in order to create new ways of being in the discipline. In this study, I examine the ways in which LGBTQA engineers are creating more inclusive and open environments for engineers and how this might increase overall diversity.

Research Context and Design

This study took place at a Research I university in the mountain west. The college of engineering enrolls almost 4,000 undergraduate students in eighteen different engineering and applied science majors, many of which are ranked in the top ten of the country. The university has been recognized as one of the top 100 LGBT friendly campuses in the United States (Windmeyer, 2006). In the early 1990s, the chancellor of the university commissioned a taskforce to investigate the climate of LGBT issues on the campus, which led to the founding of GLBTQ resource center. Since then, more GLBTQ support organizations were created to foster an inclusive environment on campus including discipline specific groups such as GLE, groups in Law, Business, and most recently in computing.

I was a researcher on an ethnographic project examining how design is organized and enacted in the classroom based on the premise that design is the defining feature of engineering (Dym, et al. 2005). During my classroom observations, I engaged with students about their experiences related to design. Neither the project nor my time in the classrooms allowed me to go into depth regarding the students' experiences of engineering as a whole; however, I developed connections with students and was invited to participate in events outside of the classroom. I met Allie during her freshman engineering projects class; through a conversation she told me about GLE and invited me to attend. After attending a few weekly meetings, I asked the club members if they would be part of my research investigating how gender is constructed in engineering. After observing and participating in the club for several months, I interviewed eight of the eleven regularly active members in order to gain deeper insight into their perceptions and experiences of engineering.

GLE: Gay and Lesbian Leaders of Engineering

GLE was in its fourth year as a club when I began my participant observations. A graduate student who had benefitted from a similar group at his undergraduate institution started it. The mission of GLE is to provide professional development, networking, and social activities for undergraduate and graduate LGBTQ students and allies. Although engineering was in the name of the club, they explicitly stated they were for students in all STEM disciplines, and they did attract members from outside of engineering. The club was promoted by its members and in communications as supporting the wider LGBTQ movement on campus, but it specifically emphasized its role in brokering connections to companies and employers that value LGBTQ engineers in the workplace. GLE met weekly during the semester to socialize and learn about professional engineering. The club officers would coordinate events outside of the weekly meetings including but not limited to attending campus-wide LGBTQ events, tours of local businesses, and social events.

After spending three months as participant observer in GLE, coupled with my observations of engineering design classes, I had developed ideas and concepts about the ways students developed engineering identities that represented the intersectionality of their lives. I decided to interview the GLE students in order to understand further how they negotiated their gendered and sexual identities within the context of undergraduate engineering education. I solicited all of the active members of GLE. At one of the weekly meetings I told the members about my interview research project and asked if they would be interested in participating. I followed my verbal announcement with an email request. Almost all of the club members agreed to be interviewed; no one specifically declined, and as I detailed below, those I did not reach were likely too busy to participate. I interviewed five participants who identified as women and three who identified as men.

The participants with their demographic information are listed in Table 1. I have included this information to support the reader in differentiating the students as I discuss them. I do not believe, however, that this table represents the complexity of these students identities. It is important to note that although these students would not object to being placed in the categories I chose, many would question the categories themselves.

Table 1 Interview Participants

Name	Gender	Ethnicity	Year, Age	Major, Minor	Position in GLE
Allie	Female	White	Freshman, 18	Chemical and Biological Engineering; Spanish	incoming vice president
Brian	Male	White	Sophomore, 19	Computer Science; Spanish and Russian	incoming secretary
Natalia	Female	White	Junior, 21	Environmental Engineering	current secretary
Alex	Male	White	Junior, 21	Chemical Engineering; Applied Math and German	current vice president
Lowell	Male	White	Junior, 21	Astrophysics; Physics	member
Mary	Female	Asian	Junior, 21	Aerospace	previous vice president
Laura	Female	White	Junior, 21	Aerospace	member
Zoey	Female	White	Senior, 23	Chemical and Biological Engineering	incoming treasurer

The interviews were semi-structured in that I had pre-determined questions that I planned to ask each student including when and why they joined GLE, how they defined engineering, and any significant events they had experienced as an undergraduate in engineering. I also designed the interview to allow the participants to bring in new ideas and questions both specific to themselves and to the conversation in which we were engaged. I met the students on campus near their classes or where it was convenient for them, for example I interviewed two students as we traveled together to a conference on being openly LGBTQ in STEM disciplines. The interviews lasted approximately one hour each. I took notes during the interviews and audio recorded them.

My positionality as the interviewer was as a critical ally. By this I mean that I had developed relationships with the students during the time I spent at GLE meetings. I knew about parts of their lives and they knew about parts of mine. They knew I was a graduate student, married with children, and hobbies I enjoyed. I knew about their extant and failed relationships, classes and instructors they disdained, and how they liked to spend a free Saturday. Our shared time together allowed me to ask questions about the nature of their experience, such as how did they feel about events and why did they choose particular actions, that otherwise might be considered intrusive by an outsider. The relationship was reciprocal. They asked me questions about my research and my perspective of engineering and I readily answered. As an ally, I was, and still am, interested in their achievement and success; this contributed to why they welcomed me as a non-engineering, heterosexual, married mother into their club. I also argue below that these students were particularly predisposed to activism and altruism in that they were always trying to support and help those around them, and would likely welcome and encourage anyone who wanted to be part of the club.

After all of the interviews were conducted, I transcribed them and each student was given a pseudonym. To ensure confidentiality, I replaced names in the transcript using <> to note where I change the name and () to add clarifying comments. After transcription, I engaged in a process of iterative and open coding to identify emergent themes that then guided my coding schemes and analysis (Cresswell, 2007). Some codes were categorical like did the student have job or do they identify as male or female; other codes were weighted by degree such as experiencing homophobia or heteronormativity. I then engaged in axial coding by relating the emergent codes to each other (Strauss & Corbin, 1998). For example, codes related to current employment, social activities, and school responsibilities were grouped together in order to illustrate their lives as undergraduate students. I used qualitative data analysis software to support my systematic review of how often codes appeared across students' interviews and within individual interviews. I organized the data into patterns by matching consistent phrases, expressions, and ideas across the data (Kvale, 2007) and relating them to themes in the literature related to gender, sexuality, and transformation through organizing.

Analysis

In what follows, I present the voices of eight students learning to become engineers who were imagining and organizing for their futures. I have grouped their experiences into themes that represent the complexity of their lives as they navigate the intersections of being LGBTQA undergraduate engineers. Each theme builds on the other. In the first theme, "engaged and altruistic," I examine who are the students of GLE and how do they act in their lives. As mentioned above, many of the programs these students are part of are ranked in the top ten in the country. However, their academic aptitude represents a small fraction of who they are. In relation to this theme, I detail what their lives look like, and how they understand themselves as engineers. Despite their diverse experiences, I was surprised by the similarities in how they understood engineering and how they approached the world. In contrast, there were marked differences in how the women recounted their engineering experiences compared to the men. Although the men noticed the dearth of women in their classes, they denied seeing explicit sexism. Each woman, on the other hand, recounted a time when her gender mattered in how she was treated in the classroom, at jobs, or by other students. It was important, therefore, to show vis a vis the second theme gender stereotypes and expectations how women grappled with making sense of sexism and their shared experience with other women, while also trying to distance themselves from heteronormative expectations. The women I interviewed found more affinity with the other members of GLE than with other members of the same sex, due in part to GLE being a space accepting of members for who they are rather than who they are expected to be. GLE actively creates an environment to support LGBTQA engineers. In the final theme that I use as a cross-cutting organizer of the students' experiences, I present how, both together and individually, the students in GLE challenge heteronormativity and attempt to create a world of engineering that belongs to them and in which they belong. They do this in part by challenging gender norms and expressing their sexuality, as well as actively trying to network with both similar groups on and off campus and with welcoming employers.

Study Limitations

GLE is a small student group of engineers with attendance at meetings varying from eight to eleven members. This small number is not likely to be representative of the majority of engineering students. Furthermore, these students purposively differentiate themselves from mainstream, heteronormative student groups in engineering. I specifically focused on GLE because they represented a different perspective from other nationally known engineering student groups such as the Society of Women Engineers. Similarly, GLE represented the interests of engineers, which may or may not align with broader goals of other gay-straight alliance groups. Additionally, I have drawn on principles of intersectionality to understand the experiences of the GLE students; however, all but one GLE student is white, thus limiting the faces of intersectionality.

The students of GLE: Engaged, altruistic and ready to change the world

The students of GLE are enrolled in academically-challenging engineering disciplines at a top-ranked university. Their majors include: astrophysics, aerospace engineering, chemical and biological engineering, computer science, and environmental engineering. In addition to their majors many of them have minors both related to engineering, such as applied math or physics, and outside of engineering, particularly foreign languages including German and Spanish. All of them came into college knowing they wanted to major in some type of engineering. In addition to having an affinity for different aspects of engineering, many of the skills typically associated with engineering were part of how they viewed themselves:

> Lowell: I was always a whiz in math and physics and all that.

> Natalia: When I was really little I liked being outside and being in the dirt and getting my hands dirty. I wanted something more active and hands-on. I knew I was smart and that I was good at math and science. Normally that's a doctor, everyone knows that's a doctor. I realized pretty quickly I did not like bodies.

> Alex: Well, I'm in chemical engineering now with an applied math minor in international engineering certificate and German. I entered as just open option cause I wasn't sure exactly what I wanted to do. I knew I liked math and science, and I was like, "Okay, I'll give engineering a shot." The money to me really wasn't a concern (money as motivation for pursuing an engineering career), 'cause I knew I was math and science inclined, so I know I would enjoy it regardless. I wanted to see exactly what I wanted to do. I knew entering that I wanted to do something with renewable energy. I wasn't sure if I wanted to be mechanical. I applied to a couple different schools with the idea of doing a renewable energy focus. When I saw that <the university> had an open option, I was like, "Yeah, I'll apply for that," cause all the freshman level engineering courses are pretty much the same.

> Laura: I'm in junior aerospace engineering right now. Picking that branch of engineering just fell into my lap. Growing up, it wasn't my dream to be an astronaut or anything. My parents weren't all that surprised when I was gonna do engineering. I was the little kid that always played with Legos growing up. I just wanted to get my hands on stuff.

The students chose engineering because the discipline valued skills they already possessed including aptitudes in math and science, was a prestigious and lucrative profession, and allowed them to engage in activities they enjoyed like designing and building.

Engineering has a rigorous and structured curriculum (Tsai, Kotys-Schwartz, & Knight, 2015). Two students in aerospace, Mary and Laura, discussed with me how the number of students in their program, aerospace, fluctuate year to year because a certain number are expected to fail and fall back a year due to the grade curving practices in which students are assigned a grade based on a predetermined distribution in which the lowest performing students fail regardless of their overall performance. For some GLE students the pressure to maintain high grades is self-imposed, and yet the students in GLE strive for balance in their academic and social life. For example, after Natalia and I discussed the demands of engineering in which she believes "it requires more discipline than most," I asked her how she fit in her social life:

> Natalia: Well, I'm not exactly the greatest student. I don't do all the reading that I'm supposed to or anything like that. I definitely make time for it (her social life). If I am stuck on a problem on homework, which happens a lot, one problem you just can't do and you just spend five hours on it. I know when to call it quits and just say, "You know, it's okay if I don't get this point on the homework." Then I go do whatever I wanna do. [Laughing] I'm a lot more free with my schedule than a lot of people are.

Natalia claims she is not the 'greatest student' and yet when I ask about her grades, she replied:

> Natalia: I have high grades. I've always had high grades. My brothers have always had high grades. [Laughing] It's more of my own pressure being—I pressure myself into—I for some reason feel the need to keep those grades as high as they are. From what I've heard from other people, and clearly people that are successful now, it's not all about the GPA. It's hard for me to let go.

In addition to having high grades and a social life, Natalia is the secretary for GLE, and has a paying job as a research apprentice in which she manages the Facebook site for her Environmental Engineering department. She is also involved in community outreach activities organized by her department to broaden participation in her field. Natalia is not alone in actively privileging other parts of her life over academics and seeing the need for balance. As Mary describes:

> I don't know if there's an ideal one (engineer), but I really do think you need a nice balance between your social life and your work/school life. A lot of the really, really smart engineers, sad to say, don't seem to have a social life. I don't think that's necessarily a good thing. I see them here all the time, like early in the morning or really late at night. They're just in the study room studying or something. I don't really know what they're doing cause I don't really do that—not as much, anyway. I think a good balance is needed because you do need those social skills. Yeah, you'll look more impressive on your resume if you have a really good GPA, but if you don't do anything outside of that, that stands out.

Laura, likewise, believes that more than your GPA matters; when asked what makes a good engineer she responded:

Laura: Honestly, my opinions are a little skewed, because I don't necessarily think the people that spend 60 plus hours studying all the time are gonna be the best engineers. I don't. They don't understand the ethical or the social impact of what they're doing. They can't relate their ideas to other people. You have to be well-versed in what you're doing, for sure. You have to be knowledgeable, but you have to have all those other traits too.

Interviewer: Other traits like what?

Laura: Like just social skills, and interacting, and writing and articulating your ideas. That's way more important to me than a 4.0. I'd rather have some cool things point on my resume other than a 4.0.

Mary sees the need to balance work and play, her academics and her social life. Laura's conception of "social skills" includes recognizing how to act in the social world. For her, 'being social' is recognizing your "impact" and how to behave in an ethical, and socially responsible manner. Similarly, Allie chose to live in an engineering dorm focused on global issues rather than the honors engineering dorm for which she was eligible citing that she thought it was "too study-intensive" and that she wanted to "look at engineering from a more broad perspective." Likewise, Lowell, a junior astrophysics major saw no need to hurry through his classes:

Lowell: Yeah. Actually, if I really wanted to, and really filled up my schedule, I could have graduated tomorrow or whatever. I took a bunch of AP classes in high school, so I came in as a sophomore credit-wise.

At this point, Lowell plans to either continue with astrophysics into graduate school, or be a "rock star" if his band, "makes it big." He completes his schoolwork on Monday, Wednesday, and Fridays before his first class at two o'clock, and practices fourteen hours each weekend with his band as the guitarist. Lowell is not the only musician; Zoe plays the oboe in the university orchestra. Despite the demands of their studies, the GLE students are passionate about, and make time for, personal interests.

As I learned from my interviews, the GLE students perform well in classes, participate in extracurricular activities, and are employed. Some jobs are more academic and related to their majors, or readily accessible on campus; for example, Brian is residential advisor in his dorm, and Alex works at a research lab in his major. Other jobs are purely to makes ends meet; for example, Mary, a senior, has worked all four years at the grocery store, Safeway. Given the time commitments these students already have, I was surprised to learn about all the various ways they volunteer and give back to their communities, both within and outside of school. There was mutual admiration among GLE members regarding their ability to help others. For example, Laura was telling me about the current president of the club:

> <He> is probably my favorite person ever. He's in aerospace too. I am so surprised by (him being an ally), just how hard he works, and how involved in all of that stuff he is while just being an ally is just amazing to me. The world needs more people like him, definitely.

The willingness to work hard for other people led me to label the students as altruistic in that they showed a commitment and desire to support others without an immediate gain for themselves. They also volunteered extensively. Some of the volunteer work is related to their academic or school interests. Under this category I include holding an office in a student club, such as Alex the vice-president of GLE, Natalia, the secretary of GLE, and Allie who serves on the local board for the Society of Women Engineers. Their altruism extends beyond positions that might serve their own academic self-interest. Natalia volunteers at the campus Gay and Lesbian resource center and has participated in engineering outreach work with kindergarteners through twelfth-graders, Laura and Mary volunteer with the campus gay-straight alliance, Allie is both a tutor and enjoys GLBTQ advocacy work, and Zoey volunteers for an organization that rescues and re-homes pet rabbits.

The GLE students are oriented to changing the world. This is reflected in their actions as well as in how they perceive the field of engineering. In Natalia's case, she chose environmental engineering because she spent part of her youth living abroad and travelling, and developed an appreciation for the earth:

> Natalia: Specifically environmental because my dad was in the Air Force, we lived in Germany for seven years. We traveled all around the world. I thought that the earth was a cool place, so. I think that with engineering that would be my best way of helping the earth out. I think in that way you can also help out people, which is also what I wanna do, but I'm really squeamish, so I was like, "Can't be a doctor. Might as well be an engineer."

Natalia differentiated engineering from other sciences because of its volitional nature. From her perspective, you must act on the knowledge you have:

> Natalia: I think with engineering you're more—in my head it's a lot more applied. You're doing the science too and potentially doing a science too and figuring out the concepts behind everything and then using those concepts to do something with it, find a solution to a problem. In my case I wanna find a solution to make this chemistry happen so the emissions don't happen or to—I think it's just more of action after discovery, is how I separate engineering from other fields.

I asked Natalia if the phrase "action after discovery" was common in her field, she told me she just made it up. It represents that knowledge or 'discovery' precipitates action. Although Natalia points to her personal experience for wanting to change the world, a humanitarian disposition was also fostered in engineering classes. For example, Alex spoke favorably of his freshman project class in which his team built a wireless, button controlled mood lamp for a man who lost his fine motor skills in an accident. In addition to saying that it was a great introduction to the principles of engineering, he saw its greater utility:

> Alex: I enjoyed it a lot. I mean, I learned a lot. It was very good introduction to engineering and I think <the professor> really ran—at least had that class—there was actually an objective, and you fulfilled that objective. You actually did something good with what you did. It wasn't just like, "Design this. Oh, it's never gonna be used again. Now we're gonna take it apart and throw it away."

Alex is contrasting his freshman project, which attempted to serve the needs of a disabled community member, and the projects that are thrown away once the freshman class is completed. In fact, after the freshman classes present their final projects, extra dumpsters are on site for many of the projects to be disposed. Alex recognized that his team did something intrinsically "good" above and beyond design for its own sake.

Allie characterized the field of engineering as, "there seems to be a general desire for changing things and helping people." Similar to Alex, she took an introductory class on information technology in her global engineering dorm that shaped her perception of the field:

> Interviewer: How do you think that class relates to engineering?
>
> Allie: It causes us to consider the possible effects of all of our actions and how it may be interpreted through different cultures and the possible unforeseen effects it might have. It's a cautionary thing to take very careful consideration with all of our actions and how we communicate with other people.
>
> Interviewer: What's the parallel in engineering?
>
> Allie: You wouldn't necessarily wanna create something that could be manipulated or used negatively very easily. You wouldn't want to try to promote something to another country that would be offensive or not fit in with the context of their culture. It's like that.

Alex and Allie connected their engineering experience and practice to people outside of their academic boundaries including community members and other cultures. They saw how engineering connects them to the social world in a similar way as how Laura described engineers as needing "social skills" in order to "relate their ideas" and understand the social and ethical impact of their design. Laura believed the engineering curriculum should provide more guidance regarding the moral dilemmas engineers are likely to face. Her upcoming internship was with a company building drones for the police and the military. I asked her about it:

> Interviewer: Do you ever think about the applications (of your work as an engineer)?
>
> Laura: Oh yeah, definitely. All the time.
>
> Interviewer: Would you have any moral objections to doing something?
>
> Laura: Yeah, definitely. I feel like a lot of the time in engineering—I don't think we get enough of that here. The ethical what ifs. This and that of engineering. It's definitely stuff to consider. Yeah, there's gonna be moral dilemmas in the workplace.

Laura's longing to consider "the ethical what ifs" in engineering further represents the agentive disposition the students have towards their profession. They believe they can "do good," "consider the effects of their actions," and make a difference through "action after discovery". Even the students who argue for "science for science's sake," argued that the knowledge we gain through science ultimately is to benefit humanity. Brian maintained that space travel is necessary to find resources we are depleting from earth that humans need to sustain themselves; and when asked about his project on the density of particles, Lowell responded as follows:

> Lowell: I think it's good just for the sake of knowledge, just having as much knowledge as we can, so we can make advancements. Science always seems to help humans more or less.

When the students spoke about engineering as a field, they exposed a tension prevalent in their discipline related to the nature and meaning of design and engineering. On the one hand, students are expected to demonstrate academic and technical skills by performing well in classes and at work emphasizing a *technicist* view of engineering (Faulkner, 2007). On the other hand, they recognize that who they are and how they understand the world matter to how engineering is enacted including how they "communicate" and the "impact" of their work. In this way engineering and design are not merely situated in social relations, but the social and technical elements of design are intertwined such that neither is fully understood without the other (Suchman, 2000). The GLE students are not passive recipients of engineering knowledge that they can then demonstrate to instructors and employers. They actively examine what it means to be engineer and how and why their interpretation affects the ways in which problems are solved.

The GLE students are motivated by individual pursuits and passions but they did not lose sight of the broader world in which they live. They care about their community, the environment, the world, and even the universe. They see themselves as problem solvers; however, as young adults they are still learning about the problems they face. The demands of engineering present technical and scientific problems, but they also face challenges of navigating who they are in relation to others. In the next sections, I explore how they see themselves and are seen by others within the engineering community both locally on campus and distally with future employers. The women I interviewed are confronted with issues related to gender more directly than the men, but they all recognize the impact of heteronormativity on their lives.

The Persistence of Sexism: Gender and Heteronormativity in Engineering

One of the pre-determined questions I planned to ask in each interviewer related to the number of women in engineering. At the time of the interviews women represented 18% of undergraduate enrollment nationwide (NSF, 2013). The university the GLE students attended had a higher than average enrollment of women, but was still less than 25%. I wanted to know if the students observed this discrepancy, and, if so, access their perspectives on the issue. All participants observed the lower enrollment of women in their program and profession.. For example, both Laura and Mary in aerospace commented that there were only ten "girls" in their senior class:

Interviewer: Tell me about aerospace. How many people are in your class or do you know?

Mary: Yeah, I do. We started out with about 120. The second year we dropped down to 100 and now we're down to 80.

Interviewer: Okay. How many women?

Mary: There's ten.

Interviewer: Oh, wow.

Mary: We know all of them. There's ten girls.

And:

Interviewer: Nationwide, it's 18 percent undergraduate enrolment of women.

Laura: Yep, it's a boys' club. *[Chuckles]*

Interviewer: It's a boys' club?

Laura: It's a boys' club.

Interviewer: Tell me about your experience, why do you call it a boys' club?

Laura: When I say it in my aerospace class—my class alone, we only have ten girls. That's it. The rest of the time, I'm working with guys. I'm lucky if I'm in a group—lab work, I'm lucky if I'm in a group with another girl. Yeah.

The women were not alone in noticing the low number of women and being dismayed by this fact. After discussing his freshman project class and about his team members, I asked Andy about his other classes in chemical engineering:

Interviewer: Yeah. What about your other classes? Do you see—

Andy: It's mainly dudes.

Interviewer: It's mainly dudes?

Andy: Oh, yeah, oh, yeah, oh, very much so. It's disheartening.

Andy was "disheartened" by the low number of women in engineering because he actively sought out and welcomed diversity in his surroundings. Lowell also commented about this in his field of physics and astrophysics:

Interviewer: Nationally there is 18 percent women in engineering. What is physics like?

Lowell: It doesn't feel like it's too high of a number, honestly. I think we have a good portion. I'm actually in a few grad classes this semester, and it seems like in one of them—I think there's only one girl out of nine. Then I think in the other one there are—actually, that one's a little better. There are like four out of thirteen

The numbers the students observed are not unexpected given the national averages. Although the men were "disheartened" and reflective about why this might be the case, none of them had a story about the effects or consequences of these numbers. I was well aware of research reporting the ways in which women are positioned as secretaries and assigned administrative tasks on engineering teams (e.g. Tonso, 1996), and yet I was still awestruck that each woman recounted their experience of this phenomenon without me inquiring if it happened. For example, I asked Allie about the ratio of women to men in her engineering classes and humanities class. She was taking 'Humanities for Engineers' in which she was one of only three women in a class of seventeen. I asked her if she thought the number made a difference.

> Allie: Yeah. Like my humanities class, that was discussion-based, so I think there was an uneven balance of viewpoints and experience and things like that. It's like when we were approaching different topics in the works that we were reading, if there was a male versus female perspective, it was an unbalanced discussion at some points.

She did not pause and wait for another question. She continued:

> Then in my intro to chemical engineering class, I've actually very rarely seen my group members. We had a bunch of group projects that we had to do, but my group just happened to do pretty much everything online together. We had our poster session yesterday, and one of us was supposed to go early and try and put it together. I'd offered to do that. I go, and there's a group of three guys standing next to my table who I assumed were part of the table next to mine—that poster. I start putting everything

together, and those guys are just standing there watching me. Then when I get to the end, they're, like, "Oh, do you need help?" I realized that two of them are my group members. They were just standing there watching.

Allie had offered to put the poster together and yet she perceived the men not helping her as a gendered act; she made the connection between the ratio of men to women to her experience of being the only woman on a team. Similarly, Mary, unprovoked, shared her experiences as a woman in her male dominated discipline. After I asked Mary about why she chose her major, I began with an open-ended question:

Interviewer: Okay. Tell me, what is it like being an undergraduate engineer? Tell me about your courses and—

Mary: Well, I've had like some—I don't know if you want me to go into this, but I've had some weird sexist interactions.

Interviewer: Tell me about it, yeah.

Mary: Okay, freshman year—I think I was in <Space> class—and we were put in these really big groups to build a payload that goes to like 75,000 feet and then you use some science related to that. One of my—my project manager, my leader, you could volunteer to be that person. That person volunteered to be that person. He would never give—there was two girls out of the six people in the group. Never gave any of us girls anything technical to do, like none of the coding, none of the building. We made posters for the class, which is kind of annoying. He thought he was all like really smart cause he graduated top of his class. I'm like, "We've all graduated top of our class, otherwise we weren't (wouldn't be [sic]) in this program." That was a little interesting. Didn't really like that.

Mary was eager to share her “sexist interactions”. I asked her “what is it like being an undergraduate engineer” and she included her gendered experience in her response. She knew I was interested in gender, which likely contributed to her response, but she also had multiple experiences where her gender affected how she was treated in engineering. She continued to tell me about her experience after this class when she joined another program related to space exploration. In this instance, a male member of the team not only dictated her actions but also treated the female project manager differently because of her gender.

> Mary: Our project manager happened to be a girl. He would never listen to anything she said, but then if the guy who is project mentoring, like the actual paid professional who works there tells him the same thing, he’ll go do it right away and be like, “Oh, yeah. Of course” and never really listens to the project managers. It’s kind of like, “Eh.” Then he had me doing—setting up appointments ‘cause we had to meet with a lot of people to run our ideas by them ‘cause we’re new at this. He had me setting up appointments, typing up—pretty much I was like a secretary in the structures department. He didn’t have me do any of the machining—
>
> *Interviewer:* This was just another student?
>
> Mary: Yeah. This was a different student. Then I think my project manager noticed this and approached me and was like, “Hey, I noticed you’re not really doing anything in this. Do you wanna switch?” I was like, “Yeah.” I switched to the science team and that guy was really good about letting me do things and splitting it up with me. That was really cool, but I feel like in general, I have a lot of instances with that. Now not so much anymore because I think they’ve more or less realized that if I’m still in the program as a girl, I know what I’m doing.

Mary is studying aerospace engineering. In order to be admitted into the major, students must meet rigorous minimum academic standards or in her words, “we’ve all graduated top of our class.” In spite of this, she recounted experiences where a woman’s ability was overlooked in favor of a man’s. Although technical work was eventually shared with her in the later project, she had to persist and prove herself by being “still in the program as a girl.” The bias Mary faced is not unique to engineering. Engineering and science have long been seen as a male domain, but a recent study showed that men enrolled in engineering have one of the highest levels of implicit academic gender bias of anyone majoring in any field, and the highest level of explicit academic gender bias of all (Smyth & Nosek, 2015). Gender bias and stereotypes were present in a common theme reported by the women: male students often dictated what work female students “should” or “should not” perform. Secretarial tasks were okay but technical or “hands-on” work was shunned:

> Laura: I had to take an electronics class, for example. That was a lot of hands on building stuff in the lab. Most of the time, boys wouldn’t let me touch the stuff.
>
> Interviewer: Really?
>
> Laura: I’d be doing the write up, or doing any of that. Any of the hands on stuff, oh no, a woman’s doing it. Stupid.

The women described the sexism they experienced as “weird” and “stupid” and although they “didn’t like it,” they persisted in their majors. For Mary and Laura, they were each one of only ten women who continued through their major. Being a woman in

Aerospace was less about each of them individually for they all had the skills or else they "wouldn't be in the program." Being a woman meant they would be treated differently because they were women. Although they each had their own incidents, there was a collective recognition that women were treated differently by other students, faculty, and potential employers. Their stories were shared amongst other women. Mary relayed an anecdote about a specific teacher that she personally did not have issues with but many of her friends did:

> Mary: The way the teacher talks to her is as if she's really stupid. If she asks a question or says something wrong then he'll be like, "Well, you should know this. It's this." I've had that input from more than just her, other girls too. Some of them are like, "Yeah, I went into office hours and I asked this one question and he talked to me like I should've known it already. Then this other guy walked in and asked the exact same question—but a dude—and the teacher, the way he talked to him was completely different."

In many ways the women accept that engineering is a "boy's club." Although they recognized that their treatment was problematic, they did not say that they retaliated in any way or reported fellow students or instructors. They continued to believe in their individual ability in a flawed system. I asked Laura if she believed engineering could change.

> Laura: I don't know. I feel people talk a lot about sexism and racism, and how that's going away. I don't believe it. After just the experiences I've had in engineering, it's become apparent to me that sexism is strong. It's strong here. It's strong in the

workplace. It's definitely out there. It hasn't gone away. Yeah, it's better, but it's definitely not—

Interviewer: Is there an event that happened?

Laura: Every job interview I've had, I've had comments made about, "It's nice to have a girl interviewing. You're the only girl we interviewed today." I come back and tell all the guy friends that I have here. They'll make comments like, "Oh," like sexual comments. They're guys. Like, "Oh, was there a couch in the interview?" Et cetera, et cetera. It's just like, "No. I work just as hard as you, if not harder. I should get the job based on merit. I've gotten comments in the workplace too. One of the guys I work with is like, "Oh, well, it's nice to have a woman around. It's great. I totally support and appreciate women in the workplace." It was nice of him to say that, but at the same time, it was like, "I don't know if that was even a necessary comment."

Laura knows that she works "just as hard, if not harder" than men in her department, and she wants that to be the measure of her worth. She does not want to be seen as the token woman who has made it in a male dominated field. Her last statement, "I don't know if that was even a necessary comment," points to a broader question of how women see themselves in engineering disciplines in relation to men: should women's experiences be defined in relation to men's? It is "nice to have a woman around" only points to the fact that it is generally always men in the workplace. The women in GLE represent a complexity of how gender is constructed within engineering. As women, they experience discriminatory practices that all women face, however, they do not want to be defined as "all women." As Frye would argue, all women share a "common - but not homogenous - oppression" (1992, p. 70). The women of GLE are still the 'other' in relation to men in engineering as are all women, but, as I explore next, the women of GLE seem to suggest that some women are not only okay with being defined by sexist stereotypes but actually perpetuate them.

The relation between the women of GLE and the larger community of women in engineering is not easily teased apart. All of the women in GLE had at one point participated in the larger discourse of women in engineering by attending meetings and events held by both the Society of Women Engineers (SWE) and Women in Computing. With the exception of Allie, who continued to serve on the SWE board, they all decided to distance themselves from those communities and position the women in those communities as different from themselves. In many ways I would characterize the GLE women's response to these other women's groups as superficial at a minimum, but definitely harmful to the larger dialogue of women in engineering. For example, somewhat innocuously, Laura said of SWE, "all those girls were into a lot of different stuff than I am." On the other hand, Zoey said she preferred GLE over SWE because SWE was too big and, "often when a bunch of girls get together it is like high school, and they are so bitchy."

The pejorative use of "bitchy" no doubt reinforces sexism. "Bitch" itself if a complicated word: most often it is an epithet against women, but is sometimes "reclaimed" by feminists (Kleinman, Ezzell, & Frost, 2009). Similarly, the ways in which the GLE women speak about other groups of women is problematic, but I believe they are still trying to make sense of broader issues of privilege and oppression, and what it means to recognize that some women benefit from race, class, and heterosexual privilege (Young, 1990). My interview with Natalia demonstrates how underneath her disdain of particular women's groups, is frustration with a patriarchal system that oppresses all women. I began by asking Natalia about SWE, she begins by saying she didn't like it.

> Interviewer: Why didn't you like it?
>
> Natalia: It's a society of women engineers. I think that it's—well I'm clearly not the—gonna be super heteronormative and be a stay-at-home wife that cooks and stuff. Well clearly not as an engineer. Seriously all they do, I think is bake cookies, different cookies. *[Laughing]* Yeah. I don't know, I just didn't like it very much and women can be really catty sometimes. There's a lot of drama.
>
> Interviewer: Yeah, there's drama?
>
> Natalia: I don't think within them. They just gossip—you know, I don't know. It's like typical women. It's too much estrogen for me all at once. *[Laughing]*

In this exchange, Natalia is defining "typical women" as "estrogen" filled homemakers who "bake cookies". Women create "drama" because they "gossip" and are "catty." Feminists have long recognized that women perpetuate damaging stereotypes of other women (e.g., Glick & Fiske, 2001), and Natalia can be faulted for this. However, she is also calling out "heteronormativity" and expected gender roles as "wife" and "cook." Natalie is rejecting the essentialization of women, but also recognizes that not all women are bothered by gender roles. The problem, according to Natalia, is that "woman" becomes so narrowly defined that many women are excluded, in particular at so-called "women in STEM events."

> Natalia: I was at <a conference> last week, and I went to one on—I think it was just women in STEM. A lot of it comes back down to the same heteronormativity of that. As a woman you're expected to get a husband and have children. That's where all these problems arise because you can't go to work or you have a child to take care of or something. I was just like—that doesn't—especially it doesn't apply to me and it doesn't apply to a lot of women I talk to nowadays. They're like, "Well I'm probably not gonna have a child. If I want one I'll adopt one. I won't be going through that nine months of where I can't work or something like that." The events are still kind of behind I feel like.

Natalia goes to women in STEM events because she is a woman in a STEM field; she faces gendered discrimination as have all the women in GLE. She acknowledges the underrepresentation of women as a problem, and being a problem-solving engineer, she wants to redefine how we develop a solution.

> Natalia: Not being a straight woman and not being—even if I were straight I know I wouldn't be super heteronormative and try to—cause I think all that stuff is crap anyway. Going to various women and whatever STEM events, this is all really heteronormative still, because you're dealing with women as what you think a woman is supposed to be. It's frustrating and it's—I kinda see it as the same thing as with—this is a silly analogy, cause I'm an engineer.
>
> Interviewer: No, it's a great analogy then.
>
> Natalia: The problems with global warming, a lot of what we're doing right now is dealing with the problem after the fact rather than solving the root of the problem, like with greenhouse gasses. Instead of trying to catch them and then push 'em in the ground and store them, don't emit them in the first place.

Natalia's analogy between greenhouse gasses and sexism suggests that we need to re-examine how we define the category of 'woman' before attempting to solve the problem of "women in engineering." Until then, we are "dealing with women as what you think a woman is supposed to be" and not the multiplicities of the way women are. It is no easy task to want to change the world when the definitions of what you want to change are contested. The GLE students are aware of this tension.

> Lowell: In my personal opinion, I feel gender and sexuality shouldn't even really be a thing necessarily. If someone's gay, they're just gay. If someone's a female, it doesn't affect anything at all. I don't know the way to go about achieving that. On the one hand, if we don't push for equality, it might never happen, but if we do push for equality, then it's absolutely distinct, like we're making that distinction ourselves. I guess there's a fine line somewhere in there. We don't want it to be defined, but then if you don't, you can't change it.

The women of GLE do not want to be a part of group that tells women how to be; neither do the men of GLE. They share in their commitment to self-definition and self-expression. The GLE students are still in the process of defining themselves, but they are taking control of this process. In the final theme, I show how these students are able to present themselves as future engineers in the manner of their choosing because of the network of support they have built through GLE.

Creating Possibility: Transformation through Visibility

All of the students whom I interviewed at some point made reference to “coming out” or making their sexual identity known to themselves or others. “Coming out” does not have a singular meaning. According to Plummer (1996) coming out can have three separate yet interrelated meanings. First, it can be a process of self-recognition and exploration of LGBTQ communities and lifestyles. Second, its most prevalent usage, it can be self-identification as a LGBTQ person. Lastly, it can be a political statement recognizing what it means to be LGBTQ in a heteronormative society. Although coming out is often thought to be an individual act, groups like GLE represent a collective manifestation of the many different ways you can be in the world: male, female, gender queer; gay, straight, asexual, or fluid. As I analyzed the GLE student interviews, I found that the different ways in which the students discussed “coming out” was tied to a great sense of visibility and recognition for themselves and other LGBTQ engineers. In this section, I discuss what this visibility means to the GLE students starting with the reasons why they chose to participate in GLE. Next, I share students’ reflections on organized GLE events that help to define who they are both individually and as a community. Lastly, I show how in building a network of support the GLE students create opportunities not only for themselves as engineers, but all future engineers thereby creating a more inclusive discipline of engineering.

I mentioned above that the GLE students are young adults. They are between the ages of 18 to 23. For most of them, they had only been “out” a few years with several of them not identifying with their sexuality until they came to college. For many of them, they know students who hide their sexuality because they are still dependent on their families financially. For example, Alex tells me of a friend who will not come out until she graduates because she is living with her parents while they pay for her school. With the exception of Allie, who researched the university specifically for its LGBTQA support groups, the other students learned about GLE once they were on campus and by word of mouth. For example, Laura, Natalia, and Mary lived in adjacent dorms; Mary learned about the club from friend and told Natalia, who then told Laura. I had asked Laura if she knew about GLE prior to coming to the university:

> Laura: No. I had no idea. I don't even think any of the queer resources were even on my mind at that time. I didn't know about any of that until I got more involved on campus. I was like, "Oh, maybe I should go to the <gay straight alliance>. Maybe I should start going to <GLE>." <Natalia> was the one that introduced me to <GLE>, because we all lived in the quad together freshman year. <Natalia> was like, "Oh, you should come to this." I did. It was good.

The students expressed wanting to meet other like-minded people with whom they could have a sense of belonging. Zoey didn't feel like she belonged in the Society of Women Engineers, but GLE was "cool" and "fun." Similarly, Alex talked about how he comes across as "annoying" but wanted people to hang out with and to be "part of the group." GLE accepted him:

> Alex: The first meeting, which was down <in a classroom>, the first or second week of school, I walk in. I was super awkward. I was like, "I don't know any of these people. I'm very out of place." I kinda fell in with the group pretty quickly. Within a couple meetings I was feeling like I was actually part of the group. Then later that year, I

> was like, "Yeah, I'll apply for a leadership position."

Alex "didn't know any of these people" but he "fell in with" and became "part of the group." Joining GLE was about both meeting new people and feeling accepted and comfortable with these new people. Natalia also emphasized the challenges of starting college and needing support:

> Natalia: I went to it mainly just to like meet people. Cause I wasn't out before coming to college. That was a first step of kind of putting myself out there and figuring out what all that is about. I think that (hanging out) was more of the focus of it. That's what it is more of to me is giving people a chance to come be part of a community that—with people like themselves that they can be really comfortable with and get—we don't really have a lot of things, but if you need help with advising, just the logistics of being in engineering school or if you need help with homework. Having that be a place where you can ask someone and feel comfortable with that I think.

Similar to how Alex became part of the group, Natalia spoke of GLE as a "community". To her it was a community of allies that could help you navigate "being in engineering school" or "help with homework." When I asked her if students could receive that support at the student center, the importance of 'seeing' someone as an ally was stressed.

> Interviewer: Well couldn't you do that at the <Engineering Student Center>?
>
> Natalia: I mean potentially, but there's no guarantee that they're an ally.

> Interviewer: I thought you said help with homework?
>
> Natalia: Right, right, but I mean as maybe a freshman, like an 18-year-old that just left high school, just is finally coming to college in a bigger town that has never been out before, never really explored any of that. To be comfortable with that and like—I mean.

Natalia juxtaposes "a place where you can ask someone and feel comfortable" with having "just left high school" and having "never been out." Attending college in a "bigger town" is a chance to leave invisibility behind and in the past, and begin a process of self-recognition and identification. As the students are discovering who they are as individuals and as engineers, they discuss the importance of being free to be themselves while having fun and finding solace with other engineers. In response to my question about what he liked most about GLE, Alex responded:

> Alex: The people. I like the people the most. They're all really fun people to hang out with. They come from different engineering fields, so we can all—but they all—most of them are from engineering or sciences, so I feel like that common interest links us together. We can all complain about the same classes sometimes. "Oh, I took this class," or, "I just took this exam," and everyone's in the same boat. It brings everyone down to a similar level. That assumption or presumation (sic) of sexuality or anything like that or gender identity is just gone. It's out the window. There's not really judgment or assumptions or any of that, and I like that a lot. It's (GLE) lets me be more open, more open, more myself, which sometimes I fear might be kind of annoying.

The students built a community that fostered open-mindedness and respect for each other by not taking themselves too seriously when they were having fun, and taking themselves seriously when they engaged in professional endeavors. Many of the events the students recounted in their interviews were about having fun and building a sense of play among the group. I detail this before talking about the professional side of the club.

The club by name and by its activities was about being LGBTQA in Engineering. Many of the activities were centered on embracing LGBTQA identity by being social with one another and naming what it means to be LGBTQA together or as Alex said, "we're here, we're queer, let's hang out." The students did hang out. They organized trips to a nearby all-ages gay bar, they had a health center speaker give a lecture on queer, safe sex-ed before going to an adult novelty store, they went to the university's queer formal, and had parties. Zoey's boyfriend hosted a party for the club where "a lot of people ended up naked." These events were important for building relationships, but when I asked, "what was your favorite GLE event?" the students would talk about activities in the engineering building where they combined their playfulness with their engineering identities. For example, the week before Easter, the students filled plastic Easter eggs with candy and condoms and hid them throughout the engineering building for non-GLE students to find. In each egg they put silly sayings like "in case you lay more than an egg this weekend" or engineering-humor, "here's to your heat exchange" but they do not reveal who is responsible for them or identify that GLE was involved with their dissemination.

The yearly lock-in was the most noted social event across all of the student interviews. Once a year, on a Friday night, the GLE students would have an all-night party in the engineering building. As an official club of the engineering college, the club officers had key access to the building and student support offices, but they never told administrators they planned to stay all night. It was called a lock-in because it was after hours and the doors to the engineering building were locked to outsiders. Lowell had attended three lock-ins; I asked him about his favorite event in GLE:

> Interviewer: Is there any event in <GLE> that stands out in your mind as your favorite?
>
> Lowell: I feel for me, it's probably the lock-in. I feel that more than anything, you really get to know the people that go to <GLE> and actually understand them, sort of.

We then talked about the recent lock-in that I attended with the club. One of the team building exercises involved a name game while hitting each other with a newspaper. It was a silly game, but it surprised me because it came after more conventional team building exercises. I asked Lowell if he liked the lock in "because you got to beat people," and he responded, "I mean that's fun, of course." Again, the combination of "fun" with "really knowing people" stood out as a defining feature of the club. I asked Lowell how the lock-in different over the three years he attended.

> Lowell: The first year I'd say was the most different. I think that's cause we had a lot of different people in charge of <GLE>. I know we did a whole section of the lock-in dedicated to gay lifestyle almost, and before the scavenger hunt part, a lot of people

> dressed up in drag, and ran around the engineering center. But the person who was really good at all the make-up and stuff, he left after that year, so that went away basically.

The lock-in was Lowell's favorite GLE activity because you got to "know" and "understand" people. The GLE students are negotiating their identities as young, LGBTQ engineers, and the people you identify with in turn shape your identity. The GLE students are learning to become engineers insofar as they are developing identities as GLBTQ engineers while simultaneously constituting an engineering practice that includes GLBTQ engineers; persons and practices are mutually constitutive (Packer, 2010). Events like the lock-in underscore how it is through imagining another world that change happens. The GLE students are creating a "new world-yet-to-become" and showing that history is still unfolding (Deneulin & Dinerstein, 2010).

The fact that there were "different people in charge" changed the events of the lock-in. The person who encouraged dressing up and drag, Emmett, had graduated. Emmett encouraged visibility by encouraging everyone to "put on make-up, dress in drag, and run around the engineering center." GLE meets weekly in the engineering building. Their meetings are held in classroom tucked away from the main corridor. The lock-in and the Easter egg hunt are times that the GLE students come out. They take over the engineering building and make it their own. A question I wished I had asked is, "what does it feel like to walk down the hallway dressed in drag versus dressed as a student?" This question would help articulate what new possibilities for their future selves were created through this activity.

A few days after the Easter egg hunt, all but one egg was gone. The single egg lay on the radiator hidden behind the main door and in front of the engineering administrative offices. For weeks after Easter, the egg remained. Thousands of students walked past that egg without noticing it, despite it being brightly colored. For me, the egg was a reminder of GLE's playful presence in the building, and yet, it also represented how some attempts of visibility may go unnoticed. Events like the Easter egg hunt and the lock-in allowed GLE students to play with visibility and invisibility. In the "lock-in" they were protected and hidden from any 'outsiders' who might disrupt their activities; despite eggs being scattered throughout the engineering building for other students to find, the identity of GLE remained concealed.

The GLE students decided how and when to be visible. One way they fostered their visibility is by extending their networks of experience into the broader engineering and LGBTQA community. They do this in part by organizing events with other clubs and schools. A few of the interviews took place shortly after students from engineering departments from four neighboring universities met on a Saturday to discuss strengths and challenges to having a LGBTQA engineering support group. I asked Allie to share her opinion of the meeting. After saying it was "interesting" and "really nice meeting other school groups", Allie elaborated:

> Allie: It was just enlightening to see how different schools approached LGBT issues and having diversity within their schools. The <school #1> students don't have a group yet, and they're trying to form one. They have a hangout place like that, but that's the extent of theirs, but they try and do a lot more visibility things. There was one guy that was saying that he frequently visits a variety of classes, including engineering classes, to try and talk about being LGBT in those environments, and answer questions, and things like that. While the kids at <school #2>—all of their professors and administration basically try to

> pretend that they don't even exist and tend to be awkward, or don't acknowledge it, or try and push it away and say that it's only within arts and sciences communities.

By meeting students from other universities, the GLE students can see why and how visibility matters. GLE has institutionalized support by virtue of being a recognized as a university affiliated student group. Along with this recognition comes access to spaces they can freely interact. The other schools are still struggling to be seen and create “visibility” by going to classes and having their administrations recognize that being LGBT is not an “awkward” phenomenon that only happens in the humanities. Making LGBTQ engineers visible is the first step in making engineering more inclusive or as Natalia said it is to have “action after discovery.” Meeting other engineering students facing the same challenges as them, is a step in broadening support for all LGBTQ engineers. In Laura’s words:

> The Saturday? That was brilliant. I loved it. I was all about it. I thought that was a really good step, and definitely will help other schools get started. It was really cool to meet some other people and see how other engineers handle it.

In addition to supporting LGBTQA engineering issues through student advocacy, GLE organizes industry leaders to present at weekly meetings, and travel to local engineering firms to learn about their efforts to create inclusive workplaces. Also, once a year members of GLE have the opportunity to attend oSTEM. oSTEM is a national organization that holds a yearly conference to support education and foster leadership for LGBTQA communities in STEM disciplines. The year Brian attended oSTEM he was a sophomore and just wanted to "get a lay of the land." Zoey, as a senior, attended with Brian in order to network for possible jobs. The year Alex attended, he took away important messages on how he planned to present himself to future employers:

> Alex: Probably the biggest take away is don't hide it. That was one of the biggest workshops takeaways - is that don't hide it. If you hide it while you're applying for a job or you're in the workplace or something like that, you're not bringing your whole self to the table, because you'd perhaps be hiding skills that are related to your LGBTQ-plus identity. That really resonated with me, so I just don't hide it anymore. Plain and simple, I don't care what anybody thinks. If somebody is going to remove an opportunity from me because I'm gay, okay, fine, I didn't want that opportunity anyway.

In other words, Alex's biggest take away is to remain visible. By saying, "I just don't hide it anymore," suggests that Alex had previously hidden parts of his identity. His experience at oSTEM made him realize that if he was purposefully hiding parts of his identity, he was likely hiding more than he thought, and would never be bringing his "whole self to the table." When I asked how he would make LGBTQ-plus identity known, he discussed listing that he was an office for GLE on his resume, and then:

> Alex: It's very convenient, because if I had that on there, and that would in some way dissuade those from offering me a position or giving me an opportunity, then I know that I would maybe have to hide it there, and I don't want that. I don't want that. I want to bring my whole self to the table.

GLE is making visible identities that have been told to stay invisible. It starts with the individual students themselves making a statement being "out". These students found the support they needed in each other to continue to learn about themselves and their field. Just as they believe engineering is about changing the world and making a difference, they too believe they can help other LGBTQA engineers.

> Natalia: People ask me why I do this a lot. I'm like, "Well, A, I just wanna do something different, and B, this is like 'Hey, I'm here. Gay people exist. It's fine. Get over it. They exist everywhere.'" Our <GLE> shirts say, "Engineering is so Gay". They're here. People are here. Everyone can do something everywhere. It's a lot about exposure and about visibility and telling—showing that people can do it, not just telling them, but showing them people in these places.

Discussion

Interviewing the GLE students reveals the tensions and intersections of gender and sexuality in these young engineers' lives. On the one hand, they provide evidence that "sexism is strong. It's strong here" and it is not going away, demonstrating that women continue to face gendered challenges as engineers. On the other hand, "gay people exist. It's fine…everyone can do something everywhere," demonstrating how engineering can be more inclusive towards LGBTQ individuals. Making sense of how practices resist change while simultaneously undergoing transformation is no easy task.

As agents of transformation, the GLE students enact prefigurative worlds, in which their desire for engineering practices that are welcoming to LGBTQ engineers make possible this future. By prefigurative, I mean to suggest that these students are "trying, exploring, rehearsing anticipating different - better - worlds" and "realising something that is *not yet*" (Dinerstein, 2014, p23, emphasis original). Through this realization, the possibility becomes *real* (Levitas, 2013). The students of GLE draw on their dispositions as "world changers" in order to both create a space and model how they wanted the world to be and enable this world to become an actuality. Local student groups like GLE are leading to formal institutions and organizations that instantiate this change and work for more systemic change. For example, oSTEM, a national society dedicated to educating and fostering leadership for LGBTQA communities in the STEM fields, began nearly the same time as GLE. It too was founded by students who felt LGBTQ students deserved structured, institutional support as they developed STEM careers (Out in Science, Technology, Engineering, and Mathematics, Incorporated, 2016).

Similarly, Lesbians who Tech was founded in 2012 as a nationwide community to support lesbians and women in technology fields with the belief that supporting all women in STEM will lead to more women in STEM (Lesbians who Tech, 2016). The correlation between a higher degree of openness to LGBTQA individuals and increased representation of women was shown in the recent survey of LGBTQA workers mentioned above (Yoder & Mattheis, 2016). Even though these organizations are forming, this does not take away from the sexist experiences the GLE women faced in engineering. Therefore, we must continue to investigate why sexism persists.

One way to examine the persistence of sexism, and the underrepresentation of women in engineering while not creating a rigid or fixed category of gender, is to draw on the concept of hegemonic masculinity, as it is understood as the pattern of practice that allows men's dominance of women to continue (Connell & Messerschmidt, 2005). Embracing this concept entails recognizing that there are multiple masculinities that are not tied to particular sexed bodies, but are rather configurations of practice that are accomplished in social action. Masculinities, and femininities, are constructed, unfold, and change through time. Because of this capacity to change, despite the perpetual underrepresentation of women, there is always a possibility for engineering, and all STEM disciplines, to have broader representation of women and more diversity in general.

Conclusion

The underrepresentation of women in STEM disciplines continues to be a problem that educators and industry attempt to rectify. What I have attempted to show is that the category of "woman" is complicated by the lived experience of women who contest heteronormative expectation of what it means to be a woman. Although definitions may be contested, it does not prevent the students of GLE of imagining, and therefore constructing, real possibilities for their futures selves.

The students of GLE, as active and engaged creators of their world, demonstrate how local, collective organization can lead to institutional and systemic change. The challenge for those of us who design for learning and educational opportunities for students is to recognize that even though students have capacity to construct a more equitable future, we cannot expect or demand change to come from students. We must, rather, provide the structural and institutional support that allows for collective organization to happen.

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CONCLUSION

In these three articles I have shown how learning, and learning of engineering in particular, is a consequential phenomenon in which participation and identification with a practice is dependent on the organization of and meaning given to the practice. In the first article I demonstrated how undergraduate engineering education is a sociotechnical system that students become tied to (or not) and that how design education is organized determines the entry points into this system. In the second article I examined how Lefebvre's spatial trialectic informs not only students' perceived experience of engineering, but also how the coordination of and for engineering learning impacts students' lived experience of engineering. In the final article, I demonstrate how it is through students' lived experience that transformation is possible by the construction of prefigured worlds.

The meaning-making and organizational features of a discipline are power-infused processes that regulate who participates, in what ways, and with what consequences. These three articles are a Foucauldian analysis of power in that power permeates all of society and is a productive force for how we can act and who we can become in this world (Foucault, 1995). An analysis of power, however, is also an analysis of freedom and potentiality. As Foucault argued, "if there are relations of power throughout every social field it is because there is freedom everywhere" (Bernauer & Rasmusen, 1988, p. 12). The omnipresence of power, or more specifically power relations, suggests that an individual can always act and position herself in relation to an oppressive form of power. It is for this reason that this research is situated in the Learning Sciences, for we are designers and organizers of learning who can critically examine the relations of power built into learning environments, and continually question and challenge for whom and for what purposes we are designing learning.

As I conclude this dissertation, I want to return to the beginning and remind the reader that learning is a process of becoming. By invoking the concept of process and learning, I am reminded of John Dewey's words: "The self is not something ready-made, but something in continuous formation through choice of action" (1916, p. 48). As designers of learning we enable and constrain students' choice of action, and therefore, who they become; the present experience we design for should have a "favorable effect upon the future" (Dewey, 1938). We must, therefore, draw on Dewey's philosophy of experience and recognize that all students bring a unique set of experiences into our classrooms and learning environments. Our challenge is to respond to the ever-changing conditions of experience, and to promote a democratic vision of learning that not only recognizes a plurality of voices and experiences, but also recognizes that democracy, like learning, is a process; there is not an end waiting to be discovered once and for all. Both are grounded in contingent human existence and must evolve accordingly.

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