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Making engineers: An ethnography of undergraduate engineering students in a project-based program

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Making Engineers:

An Ethnography of Undergraduate Engineering Students in a Project-Based Program

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Abstract

In a project-focused engineering program, undergraduate students are taught engineering skills through the 'bike project' in which students work as teams to design and fabricate a human-powered vehicle for a member of the community whose disabilities make riding a traditional bicycle prohibitive. To understand the learning that happens in the course of this project, the researcher conducted a 20-month ethnography of the engineering program, focusing on the sophomore students' organizational experiences. As a participant observer, the researcher went to classes with the students, participated in trainings, and observed them through each stage of their project. Ethnographic observations were collected as fieldnotes which were analyzed through an iterative process with other members of the research team. Membership negotiation and sensemaking emerged as salient themes for understanding the events taking place among these undergraduate engineering students. The researcher draws on the scholarship of Communities of Practice (Lave & Wenger, 1991) and Communication as Constitutive of Organization (Putnam & Nicotera, 2009) to provide a framework and vocabulary that makes sense of these themes. Using narrative, the researcher addresses how students are negotiating their membership in the engineering department, their roles on teams, and their professional identities.

Introduction

And just like that, it's May. I was there ten months ago when the sophomores were learning about the bike project, I was there when they met the client they would build a custom-designed, human-powered vehicle for, I was there when they wrestled with ideas for their project, then wrestled with fabrication. Now I'm here with them, in their eleventh hour, the day before the final product is due, the culmination of all their efforts on this bike project.

As I approach the lab that has been dedicated to constructing bikes, I see Olivia emerging, back end first, wrestling her team's bike past the heavy doors of the lab and into the hall. Olivia's team has struggled a lot this semester with unreliable team members and significant problems with the fabrication of this human-powered vehicle.

I jog over to the door to hold it open. A beleaguered looking Olivia offers me a strained smile of thanks. Her hair is falling out of lopsided pigtails and there's a deep weariness etched on her face. It looks like she may have worked through the night. Moving past me and out into the open space of the hallway, Olivia climbs on her team's bike. She begins propelling herself forward. The bike starts slowly but begins to gain momentum. Then something "pops" and Olivia drifts to a stop.

I hold the door open for Olivia again as she wheels the bike back into the lab. "Oh, Olivia," I don't dare say aloud to this sophomore who looks like she might cry, "what are you going to do?"

In a quaint college town, hours from any metropolis, 20,000 students at State University, enrolled in more than 100 degree programs, are "crafting the knowledge, walking the walk, seizing the day, and being the change," as stated on State U's website.

Among these degree programs is State U's engineering program. Designed to stand out as a forward-thinking alternative to traditional engineering education, this program emphasizes developing engineers that will be prepared to succeed in a quickly changing landscape of engineering work. The engineer of tomorrow needs to be a flexible innovator who is adept at working with others (World Economic Forum, 2016; National Academy of Engineering, 2004). To prepare students for engineering in the 21st century, the engineering department at State U has developed a project-oriented program in which students learn by doing.

This experiential learning occurs in a range of makerspaces provided by the engineering department for student use as they work in teams on required projects or make use of the resources to explore their own interests in making. In the Sophomore year of the program, students are enrolled in Design I in the fall, followed by Design II in the spring. These two courses together are colloquially known as 'the bike project.' In the bike project, sophomore students work on teams to design and construct a human-powered vehicle (the 'bike') for a client with disabilities that make riding a traditional bicycle difficult or impossible. The building phase of this project takes place in the engineering makerspaces, making this project an appropriate site for an ethnographic exploration into learning in makerspaces.

Makerspaces are becoming ubiquitous in colleges and universities across the nation but much of the scholarship in this area has been directed toward how to build makerspaces and strategize students' access and entry points into those makerspaces (Blacklock & Claussen, 2016; Levy et al., 2016; Barrett et al., 2015), stopping short at the communication and learning that are happening in maker communities. Still, there is

a small, but growing body of research looking at what students do and learn in makerspaces (see Sheridan et al., 2014, Tomko, 2019). This thesis contributes to this scholarly conversation by focusing on the communication and socialization processes occurring among sophomore students during the bike project. Employing ethnographic methodologies, I became a participant observer in the engineering community over a span of 20 months. The focus of my time in the field site was largely spent with sophomore students, but included observations of and conversations with students at every level of the program, faculty, staff, and alumni.

In the early stages of my ethnographic exploration of communication and learning in engineering makerspaces, membership negotiation clearly emerged as a salient process regarding what and how students learn in sophomore design. Some of this related to the perceived role of the bike project among sophomores as a threshold experience to full membership in the program. Membership in the program is signified by a letter of invitation students receive between their sophomore and junior year; this is the official invitation into the engineering program. Prior to this, the students (as first-years and sophomores) are probationary engineering students. To better understand the connection between membership negotiation and learning, this thesis offers a focused look at how these sophomore engineering students make sense of their work and experiences. Specifically, I examine how students actively negotiate their membership in the engineering program, and the manner in which they accept and resist the organizational values as the program seeks to "make engineers."

Becoming a member of an organization is described by McPhee and Zaug (2009) as a negotiation which is necessary for the continuing existence of the organization and a

process by which new members are introduced to the values and expectations of the organization. This perspective emerges from the scholarship of Communication as Constitutive of Organization (CCO), in which organization is evaluated as a verb instead of a noun. That is, from a CCO perspective, organization is continually enacted, and membership negotiation is one aspect of this enactment. Membership negotiation in organizations has frequently been evaluated in workplace organizations, but not higher education. When learning is the primary goal of an organization and one of the populations is transient, membership negotiation takes on different functions that have yet to be thoroughly explored in existing research. Examining the role of membership negotiation in this making-centered engineering program presents a unique and promising opportunity to address this gap.

Enacted organization relies on sensemaking (Weick, 1979, 1995). Sensemaking is a social process in which members draw on external cues to understand current events and construct narratives that guide their actions. This process contributes to the development of communities of practice (Lave & Wenger, 1991) as members self-organize into groups that share ways of making sense of the world around them, as evidenced in shared language and rationality (Taylor, 2009). This thesis examines how sensemaking manifests at different points in the bike project and differs from one team to the next. To explore the impacts of sensemaking and membership negotiation among sophomore students working through the bike project, this thesis examines the following research questions:

RQ1: What are the characteristics of learning in a team centered making project (i.e. "the bike project")?

RQ2: How do students negotiate their membership in an engineering department during a team centered making project (i.e. "the bike project")?

Overview of Thesis

In this thesis, I draw on the ideas of sensemaking (Weick, 1979; 1995) and membership negotiation (McPhee & Zaug, 2009) to complement explanations of "learning by doing" in the scholarship of Communities of Practice (Lave & Wenger, 1991). Equipped with this heuristic framework, I present a narrative of the students' experiences as they negotiate their membership in the organization, their roles on teams, and professional identities all while navigating the phases of the bike project.

Chapter one offers an overview of the sensitizing theoretical concepts that informed and guided this study. First, I highlight the scholarship surrounding makerspaces and communities of practice as a starting place for understanding learning by doing in a project-oriented engineering program. Then, transitioning to the role of the engineering department as an organization in the ongoing development of students, I explore Communication as Constitutive of Organization and sensemaking. I wrap up this chapter with a preliminary view of sensemaking as learning.

Chapter two details the ethnographic methods used in this study and the field site where this research takes place. In the methods section of chapter two, I explore the benefits of qualitative research and ethnography more specifically to address the research questions. The section dedicated to the field site, provides an in-depth portrait of the engineering program, the makerspaces, and the majors characters. Importantly, I use techniques of composite narratives and characters to both protect the confidentiality of

the community members, while enabling readers to follow the stories of a complex and multi-faceted community.

Chapters three, four, and five present a rich narrative exploring the student's experiences in each phase of the bike project. In the exposition phase of the project students are introduced to the client and the processes they will use to complete the project. In the action phase students struggle to turn their ideas into a fully operational vehicle that is suitable for the client. In the resolution phase of the project, the students reflect on their experiences and construct narratives that shape their professional identities.

Finally, interpretations and discussion are presented in chapter 6 where I revisit the theoretical lenses of sensemaking and membership negotiation to answer the research questions. I use types sensemaking to explain how learning differs at each phase of the project and explore how team types impact sensemaking and learning. I then explore how student responses to organizational values contributes to the formation of communities of practice within the organization. These interpretations are then put into conversation with the bodies of scholarship informing this study.

Chapter One: Review of the Literature

This thesis is an organizational ethnography of an engineering program, focusing on its student members as newcomers. Specifically, I explore the ways in which students move from newcomers to more full participants in an engineering community. As an ethnography, I am guided by methodological assumptions that center the voices, perspectives, and experiences of the participants first and foremost. However, as Tracy (2019) and other qualitative methodologists assert, all studies exist within a broader scholarly conversation. Thus, situating this organizational ethnography within an ongoing scholarly conversation not only provides sensemaking concepts to aid interpretations, but also demonstrates the many ways this project contributes to broader conversations in engineering education, learning sciences, and organizational communication. As such, the following section overviews relevant literatures on makerspaces and communities of practice, theoretical framework of Communication as Constitutive of Organization (CCO), and sensemaking.

Makerspaces and Communities of Practice

A makerspace, similar to and sometimes called hackerspace or fablab, is a collaborative learning space where people can experiment and create with tools and technology. Beyond providing resources for creative endeavors, makerspaces create opportunities by bringing together people with varying skill sets and levels of expertise to learn from each other. The number of makerspaces available to the general public and in universities has increased significantly in the last decade (Lou & Peek, 2016). Makerspaces are of particular interest to engineering programs as they help prepare students for the many tasks required of them in the workforce. As Tomko et al. (2017) address,

> Today's engineering students must graduate with greater sagacity than what the standard engineering curricula has to offer them. Industry desires for engineers to have talent and skills beyond applied theory and analytical reasoning. Students must be able to communicate, collaborate, integrate, facilitate, and apply what they have learned in a new innovative and unforeseeable ways. (p. 1)

The authors suggest that working in makerspaces enable engineering students to broaden and contextualize their engineering knowledge to meet the needs described above.

Previous research illustrate makerspaces are environments in which people participate, iterate, build relationships, and develop leadership skills (Sheridan et al., 2014). Makerspaces meet instrumental and relational needs of the people who frequent them and are places to explore and build community (Tomko et al., 2017). In other words, students develop confidence and efficacy in fabrication, as well as a sense of identity and belonging in makerspaces. Although makerspaces in academic settings have increased in popularity, challenges for creating and implementing makerspace programs include navigating existing policies, finding space, and working within budget constraints (Curry, 2017). Makerspaces are an attractive site of research as academe works to justify and leverage the strengths of these unbounded learning spaces.

Research into the pedagogical value of makerspaces has largely drawn on the scholarship of experiential learning, constructionism, multiliteracies of learning, and situated learning (Curry, 2017; Litts, 2015). The scholarship that emerges from these perspectives frequently describe makerspaces as communities of practice (CoP) (Tomko, 2017; Sheridan et al., 2014; Litts et al., 2016). "Communities of practice are groups of people who share a concern or a passion for something they do and learn how to do it

better as they interact regularly" (Wenger-Traynor & Wenger-Traynor, 2015, para. 1). CoP, as a concept, emerged from Lave's (1991) investigation into the nature of situational learning. "Learning is not merely situated in practice—as if it were some independently reifiable process that just happened to be located somewhere; learning is an integral part of generative social practice in the lived-in world" (Lave, 1991, p. 35). Thus, learning cannot be disentangled from one's social locations and membership within the communities in which one practices. As Lave (1991) argues, "changing locations and perspectives are part of actors' learning trajectories, developing identities, and forms of membership" (p. 36).

Lave & Wenger's theorizing of communities of practice is built upon several processes of engagement. Most central to their theorizing is the concept of legitimate peripheral participation (LPP). Legitimate peripheral participation describes the type of engagement that is characteristic of newcomers to a community of practice (Lave, 1991). Paechter (2003) describes the role of LPP:

> Legitimate peripheral participation allows a novice to take part in peripheral aspects of the practice of the community and to be recognized as legitimately so doing, while gradually being inducted into more central, often more complex, aspects of the practice. Thus, the novice practitioner gradually takes on more and more expert and important tasks, until eventually she or he becomes an "old timer," a central participant with a role in inducting new members. In this process, learners develop not just their expertise in the practice, but also their understanding of and embeddedness in the culture that surrounds it. (p. 542)

Thus, the term periphery here does not suggest a lack of engagement, on the contrary, it describes new members actively moving with intention towards full membership, conceptually similar to the idea of socialization. Apprenticeship is one important form of legitimate peripheral participation, a process in which "newcomers" come to understand all of the behaviors, values, and ways of being in a community through engagement with full members such as family, friends, peers, and faculty, among others (Lave & Wenger, 1991).

In a CoP, members bond over time as they engage in related interests and/or activities (Wenger-Traynor & Wenger-Traynor, 2015). CoP's facilitate expertise development by providing a network of support and knowledge (Tomko et al., 2018, Sheridan et al., 2014). Such modes of socialization within CoP's often happen through apprenticeship and can be seen across different types of organizations, including those found in institutions of higher education. For example, mentoring, which is demonstrated to facilitate socialization (Van Maanen and Schein, 1979), has been linked to positive outcomes for first-generation college students (Wang, 2012).

Communities of Practice and Organizing

CoP's are often situated within a broader organizational context. Within an organization, CoP's may be recognized or not, legitimized or not, and have transformative power or not (Wenger, 1998). Further, Wenger (1998) argues, that "even when a community's actions conform to an external mandate, it is the community—not the mandate—that produces the practice. In this sense, communities of practice are fundamentally self-organizing systems" (p. 2). The functions of CoP within those "self-

organizing systems" include exchanging information, retaining knowledge, and providing a home for identities (Wenger, 1998).

Patterns of communication are central to the ways in which CoP's operate; that is, they engage in "organizing" practices. Specifically, Taylor (2009) explains organizing from a bottom-up perspective in which patterned activity creates communities of practice. One way that patterned activity is organized is through the development of cognitive domains. Taylor uses the notion of coorientation to explain the development of cognitive domains: "Coorientation implies a simultaneous relationship to something to be done, and to others with whom one is doing it" (Taylor, 2009, p. 155). A unit of coorientation (Newcomb, 1953) includes the engaged members and the object of attention, such as a problem, goal, or project. The state of the object of attention is emergent and dependent on the state of the members, and the state of the members is also emergent and dependent on the state of each other and the object (Taylor, 2009).

Sensemaking, within units of coorientation and mediated by language, create communities of practice with distinct rationalities (i.e. ways of making sense), called 'cognitive domains' (Maturana, 1997). Therefore, language is a resource for coordinating action within cognitive domains. Within a cognitive domain, members share assumptions and language, as Taylor (2009) explains,

> language is itself a practice, and its rules are established, and regulated, within a community of practice. Modes of sensemaking reflect the community, not just the individual. To the extent that an organization is formed of communities, each characterized by its own practices, organization must also be thought of as a

> patchwork of cognitive domains, each privileging its own premises (unexamined assumptions) and modes of justifying belief: its own language (p. 169).

Drawing further on Maturana (1997), Taylor posits that people who can speak the language of multiple cognitive domains serve as bridges between these communities of practice within an organization. An understanding of Taylor's framework thus is helpful toward drawing connections between the foundational understandings of communities of practice and theories of organizational communication grounded in social constructionist perspectives, such as Communication as Constitutive of Organization.

Communication as Constitutive of Organization

A conventional take on the field of organizational communication has been the study of communication that takes place within an organization. With a shift in the field, inspired largely by Karl Weick's (1979) treatment of 'organization' as a verb instead of a noun (Putnam et al., 2009) scholars examined communication *as* organization. From this turn, Communicative Constitution of Organization (CCO) emerged. In this view, organizations are described as "ongoing and precarious accomplishments realized, experienced, and identified primarily – if not exclusively – in communication processes" (Cooren et al., 2011, p. 1150). One of the earliest attempts to develop a theory explaining how communication constitutes organization came from McPhee and Zaug (2000) who identified four distinct processes of interaction ("Four Flows") that work together to bring about organization. Later, Putnam et al. (2009), recognizing that "both communication and organization are abstract constructs that are difficult to anchor individually as well as interdependently" (p. 2), wrote the first book specifically on the topic to explicate the relationship. Putnam et al. (2009) used the Four Flows theory as a starting point and in

each chapter of this edited book organizational communication scholars expanded and/or critiqued the Four Flows framework. This ongoing conversation has resulted in three primary theories of CCO.

The first of these theories is the Four Flows of CCO (McPhee & Zaug 2000; 2009). The four interaction processes, or "flows" of communication, identified as constitutive of organization are membership negotiation, organizational self-structuring, activity coordination, and institutional positioning. Membership negotiation refers to the process by which membership is courted and established. The structure of an organization, as well as the values and expectations that become part of an organization's identity are the result of decisive communication also known as organizational self-structuring. "Self-structuring communication includes any process that serves to steer the organization or part of it" (McPhee & Zaug, 2009, p. 36). Activity coordination refers to organizational goals and division of labor. Finally, institutional positioning is described as a process of identity negotiation and situating oneself among peer organizations, including legitimization.

Other major contributions to CCO scholarship include the 'Montreal School' and the Luhmannian perspective. The Montreal School of CCO scholarship is grounded in the concept of co-orientation. Co-orientation, as defined in the previous section, describes the process in which at least two interlocutors focusing on and responding to an object (e.g. activity or goal) and each other, resulting in a composite identity (the organization) capable of legitimating and sanctioning its members (Taylor, 2009). Coorientation is mediated by language as a resource for coordinating action through shared meanings (Taylor, 2009). The ideas of Luhmann (2006; 2018), a scholar of communication and

systems, contributes to CCO as well. Luhmann posits that organizations as systems distinguish themselves from their environments through decision-making.

Examining these three approaches together, Cooren et al. (2011) identify six premises of CCO. The study of CCO 1) is the study of communicational events, 2) uses inclusive definitions of organizational communication, 3) assumes the co-creation of meaning, 4) includes a broad understanding of agents of communication, 5) stays focused on communication, and 6) studies both organizing and organizations. Explaining the first two premises together, the examination of communication that constitutes organization(s) goes far beyond discourse to include artifacts, performances, design, transactions, and more. As the truism "you cannot not communicate" (Watzlawick, 1967) asserts, everyone in an organization is communicating. CCO would add that everything is also communicating and is brought into existence through communication. Both material and social realities are constructed through communication (Ashcraft, Kuhn, & Cooren, 2009). "We go about daily life interacting not only with other humans, but also with nonhuman beings—textual, artifactual, mechanical, spatial, and even natural—that communicate to us as well" (Ashcraft et al., 2009, p. 18). The third premise, that meaning is co-created, speaks to the constructionist ontology that precedes CCO and acknowledges that meaning-making (and therefore organizing) happens across and between agents. The agents of communication, mentioned in the fourth premise, may include organization members, outside entities, and non-human objects. "Who and what is acting is always an open question" (Cooren et al., 2011, p. 1152). The fifth premise corrals CCO scholarship. Exploring organization may lead one to examine issues of power or material existence, to name two examples, but these can and should still be

considered through the lens of communication. The last premise of CCO captured here is the question of whether we're looking at the act of organizing or at a thing that is an organization. *The answer is both*.

Not all communication organizes, some communication disrupts organization (Schoeneborn, 2011). Meaning and authorship of meaning are established through communication in practice and may be a point of contestation and conflict (Kuhn, Ashcraft, & Cooren, 2019). A more recent turn in CCO is to examine communication as constitutive of "dis/organization" (Vásquez & Kuhn, 2019). Cooper (1986) presents (dis)organization as the counterpart to organizing. Like the rhetorical situation (Bitzer, 1992), it is described as the state of things that demands a response, a call to action. The relationship between organizing and disorganizing has been conceived as a 'light and shadow' with the presence of one indicating the absence of the other. Putnam (2019), challenges this view of disorganization and organization, describing the relationship as dialectic; either may bring the other into existence.

One way that organizing brings about disorganization is through the establishment of meaning. Banerjee and Bloomfield (2019) refer to Derrida to explain that, when meaning is established (e.g. defining 'engineer' as problem-solver) it is done through a process that selects from numerous alternative meanings that continue to "haunt" the defined element. "Negotiating meaning, however, enacts (dis)organization through a reciprocal, mutually intertwined relationship between order and disorder that draws on the indeterminacy and plurality of language" (Putnam, 2019, p. 27). A Luhmannian perspective on dis/organization moves from meaning-making to decision-making with each decision capable of bringing order or disorder. Order in one area may create

dis/order in another. PeeksMease (2020) extends this idea by drawing on the premises of Deleuze (1983; 1994) to describe the (in)stability of organizations as a result of the unrealized possibilities that continue to exist as potential in the organization. That is, the subsumed choices may emerge creating tension, tension may (dis)organize or call forth organization.

Sensemaking

The scholarship above describing CCO implicitly or explicitly includes "sensemaking" (Weick, 1979) as a mechanism for organizing. Likewise, it is only once organization is understood as a discursive practice that the need arises to situate sensemaking within the study of organizing. Sensemaking is "the process through which people work to understand issues or events that are novel, ambiguous, confusing, or in some other way violate expectations" (Maitlis & Christianson, 2014, p. 58). As a concept, sensemaking (sometimes written sense-making) emerges in Weick's (1979) early work as part of an explanation of enacted organization. Weick (1995) identifies seven properties of sensemaking. Sensemaking is "grounded in identity construction, retrospective, enactive of sensible environments, social, ongoing, focused on and by extracted cues, and driven by plausibility rather than accuracy" (Weick, 1995, p. 17). Though not mentioned in the list of seven properties, the earliest descriptions of sensemaking reveal that it is also triggered by ambiguity (Weick, 1979; Weick 1995). In the following 25 years, Weick and other scholars have added to this list of characteristics. Sensemaking may also be tied to emotion (Weick et al. 2005; Maitlis, Vogus, & Lawrence, 2014) and influenced by institutions (Weber & Glynn, 2006). In addition to sense being made, it may be given (Gioia & Chittipeddi, 1991) or mediated (Strike & Rerup, 2015).

Sensemaking has been described as a perspective, framework, theory, and process. Weick often calls it a perspective, but describes it as a process. "Sensemaking is a diagnostic process directed at constructing plausible interpretations of ambiguous cues that are sufficient to sustain action" (Weick, 2005, p. 55). There are numerous features of sensemaking that illuminate its character as a process. First, sensemaking as a process is triggered by the unclear or unexpected, and it has been likened to mapmaking (Weick, 2005). That is, people in an organization have to figure out where they have been to determine where they are going; this is why retrospection is one of the properties of sensemaking. It is more than just looking back though at the available cues (another property of sensemaking), but also ordering those cues into "plausible histories that link these previous happenings with current outcomes" (1979, p. 13). Second, sensemaking is the ability to see patterns and create them (Weick, 1995). Thus, ordering cues requires selection (Weick, 1979) because not all the available information is salient. Cues are not only selected and bracketed, but also they are defined. Weick (1995) argues that "[t]he problem faced by the sensemaker is one of equivocality, not one of uncertainty. The problem is confusion, not ignorance" (p. 27). Third, sensemaking is often studied episodically (Sandberg & Tsoukas, 2015), yet is ongoing. As a result of these features, sensemaking is key to both the formation and ongoing evolution of organizations (Weick, 1995).

Sensemaking is grounded in identity construction. Sense and self are negotiated, and changes to self will change the sense that can be derived from external cues (Weick, 1995). Sensemaking related to identity in organizations may occur on the organizational level or individual level. That is, sensemaking is triggered when the identity of the

organization is threatened (Dutton & Dukerich, 1991), or when the identity of an individual within the organization is threatened (Petrigilieri, 2011). A threat to an individual's identity within an organization may occur when they find themselves in new roles (Petriglieri, 2011), particularly if embodying those roles violates some expectation (Pratt et al., 2006). Sensemaking as identity work – constructing and enacting a professional identity (Brown, 2015) – is intensified in moments of tension (Moore & Koning, 2016). Making sense of self within a profession happens intersubjectively as interlocuters process their experiences through conversation (Moore & Koning, 2016).

Sensemaking is social. Early scholarship on sensemaking was grounded in a cognitive approach, but over time sensemaking has increasingly been understood from a constructionist perspective (Sandberg & Tsoukas, 2015). Further, the people engaged in sensemaking matter; variety leads to better sensemaking. For example, Weick (2006) references an important shift in pediatric care when doctors acknowledged a harsh reality that parents could and would abuse their children. The term "battered child syndrome" didn't exist in our cultural or medical lexicon until the 1950's. Before then, children whose x-rays revealed multiple fractures in different stages of healing that the parents couldn't explain, were diagnosed with brittle bones; brain bleeds with no known cause were diagnosed as "spontaneous subdural hematoma" (see Westrum, 1993). What predicated this shift? At a Boulder, Colorado hospital, Henry Kempe, who would eventually publish the groundbreaking article "The Battered-Child Syndrome," created teams to oversee the care of injured children. These teams included social workers. Social workers brought vocabulary and knowledge necessary to make sense of these spontaneous injuries of 'unknown' origins. Weick uses this example and others to

highlight how sensemaking changes depending on who is engaged in the process and the importance of variety. Additionally, Weick (1979) uses the phrase "partial inclusion" to describe how each person in an organization is a member in multiple organizations and groups which impacts motivation, commitments, and values.

Sense may be mediated or given. Mediated sensemaking is sensemaking that has been slowed or disrupted to allow for better outcomes (Strike and Rerup, 2015). Some interactions encourage reflexivity, which is another way of positively disrupting sensemaking (Dwyer & Hardy, 2016). In learning environments, activities that encourage reflexivity are called "sense-enabling" by Moore and Koning (2015). 'Sensegiving' has largely been studied from the perspective of management theory. It was first used by Gioa and Chittipeddi (1991) to describe attempts to steer sensemaking by providing interpretations.

Finally, sensemaking is storytelling (Weick, 1995, p. 61). As Weick points out in the following, sensemaking is the construction of narratives:

> If accuracy is nice but not necessary in sensemaking, then what is necessary? The answer is, something that preserves plausibility and coherence, something that is reasonable and memorable, something that embodies past experience and expectations, something that resonates with other people, something that can be constructed retrospectively but also can be used prospectively, something that captures both feeling and thought, something that allows for embellishment to fit current oddities, something that is fun to construct. In short, what is necessary in sensemaking is a good story.

Stories in organizations can reinforce legitimacy (Abolafia, 2010), justify actions (Brown, 2005), and explain success and failure (Vaara, 2002). When past experiences are described, positionality and identity are (re)constructed in the narrative (Vaara, 2002), thus sensemaking as narrative helps us to see the importance of sensemaking also as identity construction.

Sensemaking as Learning and Organizing

Sensemaking as a communicative process assists in the understanding of how learning and organizing are connected for students as they move from the periphery to the center of a community of practice. During socializing processes of legitimate peripheral participation (Lave & Wenger, 1991), newcomers participate in the selection and bracketing of cues for the purpose of constructing plausible explanations – sensemaking – to create an understanding of new experiences. Bosma et al. (2016) connect learning through sensemaking to the dynamic process of establishing meaning in language. Specifically, they posit that novelty, such as activities one might experience as an organizational newcomer, demands a sense- and meaning-making response, and the resultant outcomes are language and learning. Still, there is considerable debate regarding the role of sensemaking in learning. For example, Schwandt (2005) argues that sensemaking is more likely to reinforce existing cognitive frameworks than challenge them. Learning, he argues, requires reflection. Sensemaking, while retrospective, may encourage self-justification which impedes learning. On the contrary, Dwyer and Hardy (2016) push back on this noting that public inquiry into Australian bushfires manifested as sensemaking, and that this sensemaking showed evidence of learning that altered cognitive frameworks and organizational systems in order to improve subsequent responses.

Guitte and Vandenbempt (2016) assert that when considering sensemaking and learning together, two issues become pertinent: (1) the retrospective orientation of sensemaking (i.e. using the past to make sense of present cues in order to get to a desired future), and (2) sensemaking as episodic. Although Weick (1979; 1995) defines sensemaking as ongoing, it is often studied in terms of events or episodes. Indeed, describing sensemaking as "triggered" by ambiguity conveys an episodic nature. Guitte and Vandenbempt (2016), explain that there are phenomenological differences in sensemaking that help to show it as a continuous, rather than episodic process. Drawing on Heidegger (1926), they outline three modes of sensemaking: absorbed coping, detached coping, and mindful coping, which is described as living forward, understanding backward, and being in the present, respectively.

Examining the differences in modes of sensemaking illuminate nuances regarding the role of communication, intentionality, and reflexivity in learning. Thus, these varied modes offer differing implications for learning *vis a vis* sensemaking. First, absorbed coping is the state of being so presently engaged in the ongoing scene, that sensemaking is made invisible. In this mode, sensemaking "is not a by-product of deliberate and intentional actions, but the result of locally embedded initiatives that emerge spontaneously along the way" (Guiette and Vandenbempt, 2016, p. 88). When absorbed coping breaks down, the immersed observer becomes the reflective observer, deliberating and assigning meaning; this is the second mode, detached coping. In detached coping, "reflection occurs 'on action' rather than 'in action'" (Guiette and Vandenbempt, 2016, p. 89). This mode of sensemaking makes use of representations such as performance indicators (e.g. using profits to determine success). The 'engagement' of absorbed coping

and the 'deliberation' of detached coping come together in the third mode, mindful coping. Mindful coping includes the added quality of intentional non-prejudice. The mindful observer pays deliberate attention to events as they unfold while taking nothing for granted. "By surfacing taken-for-granted assumptions, mindful coping prevents shifting from perceptual processing to conceptual processing and in applying irrelevant mental frameworks to novel situations" (Guitte & Vandenbempt, 2016, p. 90).

Mindful coping is the quality of knowing that you don't know, thus reducing the likelihood that external cues will be ignored as one is not clear which of those cues will be salient. Mindful coping is necessary, in part at least, because past events may be inadequate to make sense of current events. Guitte & Vandenbempt (2016) describe:

> Just like sense is made (cognitively) by placing cues in existing frames, sense is also enacted by pulling potentialities of emerging futures into the living present, unable to fit it within prefabricated frames and requiring not-knowing reflexive attitude to create meaning and learn how to cope with it. (p. 95)

Such mindful coping, it could be argued, is critical for organizational newcomers moving from the periphery to the center of a community of practice. Such intentional and reflective sensemaking would further rely on communicative processes, such as storytelling, to shape one's understanding of who they are and who they could be within a community of practice, thus likewise engaging in the processes of organizing.

What happens when a member or newcomer is confronted with more information or cues than they can handle in a given situation? Sutcliffe and Weick (2008) offer insights to this question in their exploration of the idea of 'overload.' Overload (as in cognitive overload or information fatigue) happens when input exceeds one's processing

capacity. Overload may be prompted by too many inputs, poor capacity, high demand, or time constraints. Drawing upon the treatment of "overload" in computational sciences and bringing it to organizational science, Sutcliffe and Weick argue that overload is not a problem of too much information, but instead a problem of and with interpretation. That is, overload is experienced when one cannot effectively select and bracket the right information. The concept of overload is important toward understanding how different levels of expertise will result in different experiences and responses to being in a situation of which you must make sense.

Sutcliffe and Weick (2008) argue that sensemaking and overload change with increasing expertise. Benner et al., (1996) offer five stages of expertise: novice, advanced beginner, competence, proficient, and expert. In the novice stage, tasks are broken down and the learner does not need to comprehend or possess the skills in order to participate. The advanced beginner has enough information to realize the complexity of the work but does not yet have the skills to tackle that work. Benner et al. (1996) explain how the learner engages the increasing complexity in the competence stage:

> First they must devise a plan, or choose a perspective, which then determines which elements of the situation are to be treated as important and which ones can be ignored. By restricting themselves to only a few of the vast number of possibly relevant facts and features, decision making becomes easier . . . The problem is that there are a vast number of different situations that the learner may encounter, many differing from each other in subtle, nuanced ways, and in each a plan or perspective must be determined. There are, in fact, more situations than can be named or precisely defined, so no one can prepare for the learner a list of what to

> do in each possible situation. Thus, competent performers have to decide for themselves what plan to choose without being sure that it will be appropriate in the particular situation. Now coping becomes frightening rather than exhausting, and the learner feels great responsibility for his or her actions. (p. 39)

Competence, then, is marked by increasing awareness of possibilities, requiring the development of an approach to prioritization. Proficiency is characterized by the honing of this discernment which is evidenced by increased awareness of what ought to be done, and decreased stress over these determinations. Finally, "the expert not only knows what needs to be achieved, based on mature and practiced situational discrimination, but also knows how to achieve the goal" (Benner et al., 1996, p.42).

Even when one knows what needs to be done to achieve a goal, obstacles may arise in the process. When facing a problem that has the potential to disrupt one's operation, there is a 'repertoire of responses' that may be utilized based on the options available and stability of the system in which the work takes place (Schulman et al., 2004). When options are plentiful, responses to overload include tried and true methods, followed by improvising with the tools available. If the problem persists, one's strategy shifts to 'getting by' and containing the problem such that it does not disrupt the overall rest of the operation. When other options are exhausted, the operation is redefined to an obtainable goal (Schulman et al., 2004; Sutcliffe & Weick, 2008). Sutcliffe and Weick (2008) argue that in cases of overload, novices and advanced beginners will move more quickly through these problem-solving approaches then those with more developed expertise. This is due to better selection of relevant cues.

Research Questions

The literature reviewed in this chapter demonstrate the interconnectedness of learning, organizing, and the communicative processes of sensemaking. Indeed, they provide me with a useful heuristic framework for understanding how students learn as a process of moving from the periphery to the center in the making-centered engineering program that is at the center of this organizational ethnography. The overarching goal of this ethnographic study is to explore how students in a making-centered engineering program negotiated membership and organizational values as learners. Specifically, I focus on the role of sensemaking throughout those processes, asking the following research questions:

RQ1: What are the characteristics of learning in a team centered making project (i.e. "the bike project")?

RQ2: How do students negotiate their membership in an engineering department during a team centered making project (i.e. "the bike project")?

Chapter Two: Ethnographic Methods

"So I got me an office, gold records on the wall," Joe Walsh sings about Maserati's and mansions, while I circle the round table in my 'office.' It's not really an office, and it's not really mine. It's one of the lab spaces in the engineering department. During the school year, I'm one of a half dozen people that use this space with its collection of computers and simple meeting area in the back of the long narrow room.

It's between semesters, the winter break, so now I'm the only person using the room and one of very few people in the building at all. I could be home today. I have no obligation to be here, but I need to be here. I'm heading into the last semester of my master's program, the last semester of this ethnography of the "bike project" and I have more data than I know what to do with. I've been hanging out in the engineering spaces for more than a year. I've talked to students, faculty, staff, and alumni. I've sat through classes, engaged in training, observed group meetings, and watched as students moved from hardly any knowledge of bicycle mechanics to building a human-powered vehicle of their own. That was my "work" over the 2018-19 academic year, but it never felt like work – It felt like hanging out, chatting, and writing everything down. But making sense of hours and hours of observations, that feels like work.

At the end of the fall semester I had passed the halfway point of the second year of this project, my project, and I felt no closer to being able to write up my findings than I did in August. I had thought "if I just had more time for analysis," but digging in to so great a pile needed more than time, it needed a method that works for me. After employing some of the analytical methods facilitated by the technological advances of data management software, I decided to go with a more traditional method. I printed all

my observations out and began the slow, methodical physical process of making sense of the data. Thus, I began a process that raised more than a couple eyebrows, cutting my observations into small strips and sorting them according to themes.

This is where I found myself listening to Joe Walsh on a cold winter day, pacing amid my mountain of data made manageable by cutting it into strips of paper. In my hand I hold a strip of paper, a quote from a student, that says "Last semester was more stressful because it was just a lot of information but this semester, the last year and a half falls together. Once you see how all the pieces fit together and are important, it's motivating. Seeing real world applications pushes you to keep going—but I only realized that in the last couple of weeks." I circle the table a few times before placing the strip of paper on a torn-out piece of notebook paper with the word "SENSEMAKING" scrawled across the top. Reaching for another strip of paper I feel pangs of excitement. An outsider looking at this table might see a mess, but I see, a story!

* * *

Following the approval of the Institutional Review Board, I used a variety of ethnographic methods as part of a National Science Foundation supported study to explore the intersections between membership negotiation, sensemaking, and learning in the context of one makerspace community of practice. Specifically, I conducted participant observation and ethnographic interviews throughout a 20-month period as I immersed myself in two different sophomore cohorts who were engaged as newcomers in a making centered engineering program at a large public university in the south. Immersing myself in this making community, I participated alongside students, albeit without the grades, evaluations, and stressors that they faced, as they moved from

newcomers to full-fledged members of the community of practice. Importantly, not all students made the transition to become community members; attrition is part of the socialization story of this particular making community. In this chapter, I describe the epistemological assumptions of the qualitative methodologies that guide this thesis, the features of ethnography as a body of methods generally and the practices I used specifically, the analytical procedures used to forward interpretations of the data, and finally the criteria for trustworthiness and the strategies I used to ensure a high quality ethnographic study.

Ethnography as Methodology

Ethnography is the study and writing of people and cultures using the ethnographer as the research instrument (Conquergood, 1991). Ethnography, as a form of qualitative research, embraces subjectivity, explores phenomena within cultural contexts, captures data that could be missed in quantitative research and is well-suited for the naturally curious as they follow emergent leads (Tracy, 2019). The methods that make up ethnography are immersive and embodied and rely upon processes of observation, interaction, and interpretation. Ethnography is used to answer the question "what is happening?" in a space or in a community (Tracy, 2019). It is a descriptive methodology that builds theoretical explanations by relying on an iterative process of moving back and forth between observation and interpretation as your data set expands and your understanding is refined (Conquergood, 1991).

Ethnography is a situated methodology in which the researcher occupies a particular role in the community studied and immerses oneself in the everyday life of that community. There are many stances or roles that the researcher might occupy when using ethnographic methodologies. For example, the researcher may observe from a pre-

existing role within the community as a complete participant, thus as a member of the community and as a researcher, or from a position outside of the community as an observer that does not participate nor fully interact with the community (Tracy, 2019). The roles and practice of participant observation fall between these two extremes. Participant observation places the ethnographer in the middle of what is happening, where the researcher negotiates a role or roles within the community from which to observe and participate in the community itself (Lindlof & Taylor, 2019). Such a standpoint affords the ethnographer the opportunity to gain new insight by mirroring the activities of the people being observed and helps establish rapport within the community through shared experiences. Tracy (2019) calls this role a play participant, as the researcher engages in the activities and embodies the experiences of those who are full members of the community studied. As a participant observer in the engineering department at State University, I sat with the students as they learned in their design courses, was with them as they work through fabrication challenges, and enrolled in and completed the same trainings for tools in the makerspaces. Thus, I had access to and was trained to participate in all the same makerspaces as the students in the sophomore design courses.

In addition to observations made in the various makerspaces as a play participant, I engaged students in informal conversations about their experiences in the makerspaces. These informal conversations are called ethnographic interviews (Lindlof & Taylor, 2019). I believe there is no better source for understanding how students are navigating engineering education and negotiating their positions than the students themselves. In these ethnographic interviews, taken in the field, students often spoke about the work

they were doing to fulfill their requirements as engineering students, their emotional states, their feelings about the program, opportunities for them outside of the program, and their hopes and fears. It was also not unusual for students to volunteer information that I had neither yet considered, nor asked. These extemporaneous and unsolicited musings of students revealed the beliefs and values that intertwine with their understanding of engineering, both in the context of the department and as a profession.

During these ethnographic conversations I jotted down what Lindlof and Taylor (2019) call "scratch notes." Later those notes are transcribed into expanded field notes. Those de-identified field notes are shared with the faculty advisers on the research team and with senior student researchers during weekly research team meetings and enhance the credibility of the ethnographic work as we participate in what are called peer debriefings (Barber & Walczak, 2009). These peer debriefings with the team, as well as member checks with informants in the field, may support or challenge the tentative interpretations being drawn from my time with students. This is an iterative process of data analysis. The iterative process that has been established is as follows: observations are collected; on my own I analyze these observations looking for emerging patterns; my interpretations are discussed with the faculty advisers and other researchers; questions emerge from team meetings that refine what I am looking for in student experiences; returning to the field I have new questions to ask students that clarify or fill in the gaps of the previous observations; in the field themes are clarified and new themes emerge. This process continued until theoretical saturation was reached. Theoretical saturation is the point at which no new themes emerge from the research methods employed at this time and place exploring this particular topic (Glaser & Strauss, 1967). The research questions

proposed in this thesis are a product of emergent themes in the initial stages of data collection and preliminary interpretations through analytic memos and peer debriefing. Data collected in the form of expanded de-identified field notes and ethnographic interviews form the data for this thesis.

When assessing the overall trustworthiness of qualitative research, Tracy (2010) calls on researchers to consider the following: worthy topic, rich rigor, sincerity, credibility, resonance, significant contribution, ethics, and meaningful coherence. These criteria address the entirety of the qualitative project from the topical and theoretical conceptualization, to the representation of the data or the telling of the stories in the final research report. As expressed above, the worthiness of the topic and value of contribution to a larger body of scholarship resides in the phenomena of learning in makerspaces that interacts with sensemaking in organizations that is widespread but not well understood. The rigor, sincerity, credibility, and ethics of this research is rooted in the intersubjectivity of interpretations that emerge from a team of researchers dedicated to discovery. The coherence and resonance of this research manifests as a rich narrative of student experiences.

The Field Site

Learning is demonstrably tied to sensemaking and membership negotiation for students navigating the bike project. Organization is both the outcome and context of these two processes. In this section, I will first elaborate the context of this ethnography: the engineering department. The engineering department possesses an identity that stands out within its discipline. The organizational values of the department are communicated to the students through the curriculum, physical spaces, events, and other members of the

community. Responding to these values is part of membership negotiation. Following the elaboration of the field site, I will introduce the characters that one might come across in these spaces as this ethnography transitions from explanation to narrative.

The Engineering Department at State U

Engineering is a small department at State University. Nestled between two mountain ranges, State University contributes two-fifths of the population to the surrounding city, Townieburg. Just beyond the town of 50,000 are rolling hills of rural farmland where herds of cows and poultry houses dot the landscape. Many students who come to State University are from the heavily populated and wealthier metropolitan area that is a few hours' drive away. Other students come from nearby states, surrounding counties, or internationally. As is the case for other universities, tensions exist between the contributions and demands of State University on the surrounding area. State University promotes engagement among their students and highly encourages all students participate in some form of high impact learning activities, community, and civic engagement. This community service focus results in thousands of spider-like strings of silk that float from campus to community organizations as students fulfill requirements and a sense of purpose.

Each year, roughly 150 new students declare the engineering major at State U. Considerable attrition is the reality of every engineering program. At State U, rates of attrition in engineering are impacted by the design of the program. Unlike many other engineering programs throughout the nation, there are no prerequisites to enter the program. Anyone can attempt the major regardless of their background or the skills that they may or may not have developed to prepare them for engineering. For students lacking technical skills, particularly math skills, the road to a degree in engineering may

take longer, but that will not block them from embarking on the journey. Many students who leave engineering, particularly during or just after the first year, have simply matriculated to other majors at the State U after realizing this engineering program isn't what they want, or perhaps expected. By the junior year in the program, enrollment numbers drop to roughly 80 students. Currently, enrollment in the junior class is capped by the department at 85, reflecting the resources and faculty available in the department, but each year the number of students progressing falls just below that number. There are currently 21 faculty and staff, which includes instructional faculty, academic advisors, lab technicians and managers, and administrative staff, supporting students as move through the program. The size of the department and the potential for students to build meaningful relationships with faculty and staff is a selling point of State U engineering.

Established a little more than a decade ago, State U Engineering is young as far as departments go. When the department was conceived, there was an understanding that it would be competing for students with the large, well-established Tech Institute. This department could not simply be a smaller version of what was already available to students interested in engineering in the state. Instead, it had to offer an alternative approach to engineering education, a better approach. To stand apart, Engineering focuses on equipping engineers for the 21st century, arguing that the industry has changed but engineering education has been slow to reflect these changes. To accomplish this, the program is project-based, engaging students to learn by doing, and encourages students to personalize their education around their passions. There is greater emphasis on idea generation and the design process than what may be found at other universities. Though in the minority, they are not alone in their efforts. State U Engineering is part of

a network of engineering programs with a focus on developing an entrepreneurial mindset.

The department expends significant effort into creating a program identity. Importantly, at this stage in the department's development, efforts to craft an identity that stands apart from other engineering programs, and even the rest of the University, are reflected in the physical spaces, curriculum, departmental events, and communication with internal and external stakeholders.

Communication with Internal and External Stakeholders

Communication from the department is shaped by the faculty in class, through social media posts, direct messages from the head of the department, on posters that hang in the halls and spaces, and from the students themselves. Messages in class communicate what it means to be an engineer. For example, one professor reminded students that when they're engineers it will be their name signing off on projects. This professor was communicating to the students the value of their reputation and encouraging them to listen to themselves. Importantly, not all faculty members hold the same definition of what it means to be an engineer; the professors' differing descriptions of the professional work for which the students are being prepared reflect those contrasting ideas.

Go to any engineering department's university website and you will see descriptions of interesting things students can do as part of that program. For larger, well-established programs, you're likely to be met with announcements about special awards or opportunities bestowed upon the department or faculty members. However, centered

on the page, State U Engineering's website has a message directed right to potential students.

> You want to make a difference, you want to create groundbreaking solutions, you want to have an amazing career, and you know engineering is a great choice, yet it's hard to know exactly what your world will look like when you graduate. We offer one of the nation's truly modern engineering experiences, providing curriculum, faculty, and spaces that give you the engineering knowledge, skills, and attitudes needed for success. Our undergraduate degree program is designed to help you turn your ideas into real solutions for the planet, society and industry but also prepare you with the adaptability needed for career success in the 21st century.

This message reflects a student-centered approach to engineering, personalization of engineering education, and other values held and promoted at State U Engineering.

Physical Spaces: The Makerspaces

The engineering department is visibly different than its department neighbors contributing to a sense of community and ownership for engineering students. The physical spaces of the engineering department were remodeled a few years ago. The remodel was recent enough that the senior students remember the time before, when there wasn't designated space that felt like their own. Physically, the engineering department is situated below and between other departments that are part of State University's Science and Technology College. One outcome of the remodel is the clear demarcation between the engineering spaces and the rest of the building in which it resides. The front hallway *looks* like the rest of the engineering department but there are many students from other

majors using that space, so it is unusual to find engineering students there. The hallways that comprise the rest of the engineering department provide access to numerous study rooms, the faculty offices, and multi-functional "classrooms" called studios. The spaces are designed to be multi-functional. There is no clear distinction between makerspace, study area, and classroom. These hallways also hold numerous labs; labs are spaces with designated purposes.

Directly below the main floor of the engineering department in the basement are more labs and makerspaces for the engineering students. All the rooms upstairs and down are designed with large windows allowing the activities going on inside clearly visible to anyone who walks by the spaces. Walking around downstairs you can see a fabrication lab with power tools best used for working with wood, a machine shop with mills and lathes for cutting and shaping metal, a room full of soldering stations, or a makerspace with 3d printers and vinyl cutters where students can hang out to do homework or work on a project just for fun.

The spaces in the engineering department communicate. A large flat screen monitor in the front hall cycles through the messages reminding students that this program is unique, like them. The spaces speak to anyone who may enter them. For the bike project one year, the Sophomore students designed and built a bike for an 8-year-old child with cerebral palsy. The child's mother recounted the process in a blog. The mother noted that her child experienced great delight entering the bike lab where they would make choices for the final design. On the walls around the room hung more than a dozen posters all about the client. "She was awestruck, it was practically a shrine!" The mother also notes that strewn about amid the twelve completed human-powered vehicles, were

bike parts everywhere. The students could be required to keep that workspace in better order, it would be annoying but not unheard of. They have to clean up after themselves after every time they use the other makerspaces, but the bike lab is theirs, and the mess communicates that and more.

In order to gain access to many of the spaces, students must complete an online safety quiz. This quiz communicates important information to students about how the spaces can be used. Beyond communicating, the quizzes and resulting access confer and sense of legitimacy that is experienced whenever a student swipes their student ID and hears the high-pitched beep indicated permission to be in the space. Locked doors keep outsiders out, unlocked doors communicate to students that this is their space, they belong.

Curriculum

From the website to tours, the quality promoted most about the program is that it is characterized by project-based learning; learning by doing. Much of the project-based work takes place within the design courses sequence that students follow. The engineering curriculum includes the six-course sequence of design classes beginning sophomore year with Design I and II ("the bike project"). Even though the design courses officially begin during students' sophomore year, the principles of design taught at State U are introduced to the first-year students. First year students learn about stakeholder analysis, communicating ideas, visualizing, analyzing, measuring, and testing. Values like sustainability and human-centered design are introduced early and reinforced often. In Design I and II, the bike project, students are led though the phases of design as taught at State U: Empathize, Define, Ideate, Prototype, Test.

Taking the place of design courses in the junior and senior year, capstone projects are the culmination of the design curriculum. In groups, students pull together all the design tools with which they have been equipped to accomplish a sponsored project. The students have an advisor to answer to and to get guidance from, but are otherwise responsible to make sure they are engaging in the design process in such a way to have a final product, service, or process to formally demonstrate at the department's annual exhibition, FabCon, before graduation. These two-year projects take many forms. For example, students may be on a team designing wells for a village on the other side of the globe, or a team developing a program to teach design principles to local elementary school students. They may be on a team building a car for an annual competition that takes place on the other side of the country, or a team designing a better coffee grinder for a local coffee shop. In capstone projects, students ideally get to pursue a project of particular interest to them that will further their academic and career aspirations.

Events

Each year, the students present their projects to each other, faculty, family and friends, and Engineering partners at FabCon. FabCon is an on-campus event at which students are required to attend and present their projects. That it is required makes it no less exciting for students who look forward each year to having more impressive work to show off as their skills develop and the projects become more complex. As one Senior student expressed, "I didn't have much to show off my first year at fabCon. I spent most of my time looking at the cool projects the upperclassmen were doing for Capstone. Now it's my turn to have the cool project."

Students are well-prepared to present at FabCon by repeated practice, as they participate in smaller, frequent presentations that are required in class and as part of Capstone projects. Presentations, particularly Capstone updates, are notorious for generating an abundance of constructive criticism from panels comprised of faculty members. During presentations students need to be able to effectively promote their ideas, communicate accurate technical information, and demonstrate that they understand where they are in the design process and how they are going to continue moving forward. Even a "good" presentation is bound to elicit many questions from the panel and leave students feeling interrogated. Still, having frequently presented their work throughout the process, students are prepared when parents, industry partners, peers, and faculty visit their designated spot at FabCon. They are prepared to explain the process, answer questions, and justify the importance of their work.

The Bike Project: Sophomore Design Course Sequence

The bike project emerged from a series of conversations between an advocate for people with disabilities and a few engineering faculty members. The advocate, himself a member of the faculty in another department, had approached the engineering department to explore the possibility of using the talents of the engineering students to help some members of the community. He recognized a gap between traditional bicycles and wheelchairs. What if there were something in-between that operated under the power of the user like a bicycle, but could accommodate the specific limitations of the user? As a person with cerebral palsy, the advocate became the first client, and the bike project as it is now known was born. It was a success, and a decade later is considered a hallmark of the program.

The bike project evolves over time. A not yet mentioned value that is communicated in the design of the curriculum is to never get stagnant, to keep improving. As such, even across the two academic years in which I engaged in participant observation there are notable differences in how the bike project has been structured. Since the majority of my observations come from the first year of the ethnography, the description of the project here reflects the way it was structured in the 2018-19 academic year.

In the first semester of their sophomore year, students work in small teams of 4 or 5 students. This semester is focused on concept generation. That is, during the first half of the bike project students don't pick up any physical tools except on the day the bike expert comes in to lead them through a bicycle tear-down to teach them the basic mechanics of a bicycle. Their time instead is spent developing specifications for a human-powered vehicle based on stakeholder statements. When the students talk about the difference between the first and second semester, they describe the second semester as when they actually get to do stuff. As one student expressed, that is when the works moves from their heads and paper and into their hands.

The second semester begins with assigning students to the larger teams in which they will work for the remainder of the project. Once the teams are established and roles are assigned, the students essentially redo the entire first semester's work in a week. They aren't really redoing everything, but that is how the professors and students describe it. Most of the first semester is devoted to learning how to generate a preliminary design and mining for the specific needs of the client that will guide the process; that work isn't redone. There isn't a new client to learn about and the specifications are refined

according to their design choices, but don't need to change much. They do, however, have to take the design ideas each of the team members carried in with them from the previous team/semester and come up with one design to move forward on. That preliminary design will be tested and improved through a series of 'proof of concept' assignments. Working with a budget of $400, the students generate a bill of materials for their bike. The materials are ordered in the weeks leading up to Spring break.

When students return from Spring break, they must work together to turn their purchased materials, recycled bike parts from the lab, and parts they may have machined in the shop downstairs into the "alpha prototype" of their human-powered vehicle. This is a hectic time for the students and in the spaces. The students have a couple of weeks after the alpha prototype to make improvements and present the beta prototype to the client. From the completed beta prototypes, the client will select their favorites design(s) and a composite of all the best designs will be produced for the client over the summer. The final product, designed and built by one of the Sophomore students who will be hired to work on it over the summer, has nicer material purchased just for this purpose and the quality is what you would expect if you were purchasing a bicycle from any reputable manufacturer.

The Players: The Characters in the Community

Over the course of 20 months, I have interacted with dozens of people informing my observations. To aid in reading the ethnographic interpretations in the chapters that follow and to protect the confidentiality of the member of this community, each character is a composite of many different people who share similar features and experiences in the bike project. Below is a description of the central players – the characters in the story – in

the spaces where my observations took place along with an explanation of how many, many people are composited into a few key characters who can be followed through the story arc of the bike project described in the following chapters.

The Client

In the last decade, clients for the bike project have included young children and grown adults, members of the university community and members of surrounding Townieburg. The one thing that all the clients have in common is that they are not able to ride a traditional bicycle. It may be any combination of mobility and/or sensory disabilities that restrict the clients ability to operate a bicycle and it is up to the students to get to know the client well enough to determine what type of human-powered vehicle will meet the client's specific needs. In this student-centered thesis, the client is simply referred to as "the client." That this thesis is student and not client-centered makes sense to answer the research questions, but also highlights a tension throughout the project that exists between the needs of the client and the needs of the students. As will be shown in the following chapters, the client's centrality in the project fades in and out. The bike project is human-centered design and great effort is taken in the first semester to get students to move beyond a superficial understanding of their client. During the building phase of the project, the client's input becomes even more important. When the dust settles at the resolution of the project, the students revisit the client's story and find their place in it.

The Expert

The expert is a composite of the non-faculty people the students turn to throughout the project. These people play a vital role in the bike project and in the

students' learning experiences. Only one of the experts is referred to by their own designation in the narrative below: the bike expert. The bike expert has been building and repairing bicycles for decades and has been involved in the project from the beginning. Some of the final products that go to clients in the community end up in the bike expert's shop for repairs and regular upkeep. More than anyone else, the bike expert gets to see the long-term impact of this project for the clients.

Other non-faculty support are simply referred to as "the expert," and may include State U staff and student employees who work in the engineering makerspaces. Student employees are also engineering students who have applied and been hired on to help manage the spaces, they are knowledgeable about the tools and the rules. Whether it's explaining to a student what type of curves can and cannot be milled in the machine shop or what types of metals can be welded together, the expert can be relied on to offer guidance and save students some grief. The makerspaces are their classroom and any student who wanders in is their student. The students describe the expert as approachable, skilled, and helpful.

Faculty

In the first semester of Sophomore Design, students may have been taught by one of four professors; in the second half there were two faculty members teaching three sections. Of the four professors teaching the first semester, two were women, two were men, two had taught the class before, and two were new to the department. In the second semester, one professor was a woman, one was a man, one had taught the class before, and one had not. In addition to the faculty members teaching the course, students may go to any of their professors throughout the project for advice, to complain, or to seek

support. Faculty members vary in teaching style and understanding of the project. When it is relevant to consider these differences, they are highlighted. Otherwise the role is simply characterized as "the professor."

Although the professors' time is largely taken up with communicating ideas and processes to students, their role extends beyond explaining Pugh charts and center of mass calculations. As the faculty teaching design courses in an engineering program emphasizing project work, the professor plays a role in communicating the values of the department to the students. The quality of relationship the students build with the professor can be indicative of flourishing socialization into the views promoted by the department. Students who push back on the values of the organization may seek out relationships with professors or experts unrelated to the design courses.

The Researcher

Since the methods sections deals thoroughly with how the researcher conducts an ethnography, this section is devoted to the researcher's positionality. The researcher, from here on out, is referred to simply as "I."

I am a mom. It's the first thing that comes to mind when I think about who I am. Perhaps, the supremacy of "mom-ness" in my identity is related to how much of my life is currently taken up with tasks related to the role. My children are small and needy, as can be expected of all toddlers and preschoolers. In the engineering spaces, my identity as a mom surfaces when I see students who are sick, sad, or stressed. When I see a student dragging themselves to class and ask how they're doing, am I asking as an ethnographer or as a mom? I am both. I keep snacks in the room where I interview students. I

frequently take time to admire people's work and tell them I think they're doing a good job. I feel invested in the students' success.

I am a non-traditional student. This means that I traverse a liminal space between students and faculty. My age and experiences, as a mom, as a person who has already worked for decades, as a person with many life experiences, aligns me with the faculty and staff in the engineering spaces. My role as a student with all its demands—reading assignments, written responses, presentations, deadlines, finding a parking space and getting to class on time—aligns me with the undergraduates in the engineering spaces. Throughout the day, I may oscillate between peer groups.

I am a social constructionist. I recognize the power of how we communicate to shape our lived reality. I come into this work with a BA in Sociology and a MA in Communication and Advocacy in progress. Issues of identity and culture stand out to me.

I am the researcher. I care about the people who have shared their experiences with me over the course of this ethnography and I feel a deep sense of obligation to (re)present these experiences fairly and meaningfully. I care about this project and the quality of my work. I second guess myself a lot but at the end of the day, I know how I have labored over this work.

The Students

9:15 am, ugh, I'm late again. It's two months into the semester and I still haven't gotten the hang of getting here early enough to find a parking space in the same region of campus as the engineering department. Slightly out of breath from my walk, I drop most of my stuff off in the lab that is headquarters for the research team I was hired onto for a

graduate school assistantship. Before I turn around to leave the lab, I grab my laptop and notebook to capture field notes and head to the Tuesday morning Design I class.

As I approach the studio where class is already underway, I spy Hailey turning the corner at the other end of the hall. The backpack and coat she's wearing suggests she hasn't been in the classroom yet and is also running late. Her tardiness has done nothing to dim her characteristic cheerfulness though, as a smile spreads across her face when she sees me. We meet at the large glass studio door that has been propped open for latecomers like us. Hailey's smile momentarily drops into a confused expression as we observe simultaneously that there is no one in the room. The room isn't empty though, around the modular tables are jackets, a few backpacks, and other assorted student paraphernalia. But where are the students?

Moving into the room, I roll a chair out of my path that had clearly been pushed away from a table when someone stood up. Everything in this room rolls, the triangular wedges that when pushed together make round tables, the twenty-five or so seats that can be folded up pushed together to form tight, neat stacks out of the way, even the infrequently used lectern up front can be easily moved. In a matter of moments, everything in this room can be completely rearranged for some other purpose than "classroom." The glass dry erase boards lining one side of the room along with the mounted projector screen denote the "front" of the classroom. Yet despite how easily everything can be moved, each time I come in here, the tables, chairs, and lectern are all situated in the same exact positions. With this set-up, everyone sits with their backs to the large windows facing the main hall where students from the nearby departments pass through. Having been in this room almost every week since the start of the semester, my

first semester as a graduate student, I don't even notice the students walking by the windows anymore. Except now, I intentionally look out the windows in the back of the room in my search for the missing Sophomores.

Hailey has moved into the room and around me. She notices before I do that the door on the opposite side of the room is open. For most class periods, that door stays closed. We move through the closet-like space and into the adjacent lab. Mystery solved. Wearing safety glasses and crowded around two of the tall tables on the opposite side of the neighboring room are the missing students. I've passed this room numerous times. People call it the "bike lab," though the sign on the door reads "Sophomore Design Studio." Like most of the rooms in the engineering department, large glass doors and windows make this room as much a showcase as a workspace. However, this is the first time I've actually seen bikes in the bike lab. The room hasn't had much material in it yet this semester, just adjustable-height tables and tall metal stools, and on one side large metal cage lockers, but not much else. Now, however, a dozen or so bicycles are propped around the room and toolboxes, once the lonely occupants of the large cage-like lockers, are placed at the ends of each table.

I rest my laptop next to a toolbox and find a place to stand behind the crowd with notebook and pen in hand. I'm new to taking field notes, but today presents an exciting opportunity. I'm conducting an ethnography of Sophomore engineering students in makerspaces; that's my role on the research team, but every week I've joined the class thus far has been lectures and small group work in the classroom. Finally, though, here we are, toolboxes and bicycles at the ready. I missed the start of class so I'm not sure what's happening, but I write in my notebook, "someone is here, doing a presentation,

there's a diagram of a bike on projector screens on three walls so you can see from anywhere in the room, everyone is listening to a guy talk about how a bike works." The guy, I learn, has been a bike mechanic for decades, owns a local bike shop, and has been part of the bike project since its inception. He's showing the students how to take the handlebars off the front of a bike and pointing out the marks showing the regulatory requirement that this part of the bike fit at least "this far" into that part of the bike so it doesn't break when driven.

"I wish I had more time to teach this to you because I'm about to confuse you badly with this next topic," the bike expert tells the students. I do my best to capture as much of the presentation in my notes as I can and then remember that I'm supposed to be observing learning in makerspaces and try to capture what the students are doing.

I jot in my notes that the students are listening attentively, but then I notice one student is not. Someone I haven't met yet. Hanging back from the rest of the crowd this solitary young man's eyes scan the posters on the wall. He seems a bit bored with the presentation and I wonder if he feels he already possesses the skill that is being demonstrated?"

I continue scribbling notes as the presenter instructs the students to work in their groups of four to dismantle and then put back together the front of the bike just like he has. The students disperse from the tables closest to the presenter and move towards the toolboxes and bicycles around the room. Alexis, whose long hair is tightly braided today in anticipation of being in the bike lab makerspace, stops in front of the closest bike waiting for the other members of her team to notice and join, the other students gather round and Alexis pops the top of the toolbox open.

"Let's start with the handlebars," Alexis leads, adding to one teammate, "can you record our progress in the memo?"

"Okay," the student dutifully replies.

"It's due at the end of class so make sure you capture everything as we go," the other student doesn't seem to mind Alexis's command of the situation, but just to be sure Alexis adds, "if you need help figuring out what to write just ask, I'll help you."

"Not this one," Jacob says to another student passing the bike to which I'm standing closest, "let's use that bike." Two other students exchange glances. One person's glance communicates annoyance, but it is met with shrug that says "choose your battles," and the three move on to the bike Jacob suggested.

Olivia stops in front of the bike Jacob rejected with her team members. "I have a bike like this one at home," she tells me, While she's telling me this, another person from her team opens the toolbox and starts rummaging for the tools they need. I move in close and grab my laptop from where they'll be working. Along one wall are a row of wooden cubbies that seem a safe enough spot for my laptop. Tucking my laptop there I turn and see that I'm standing between Cody's team on my left and Hailey's team on my right. On Hailey's team, I'm excited to notice, stood the unnamed student who doesn't think he needs to listen to presentations.

"What are you guys doing?" I ask Hailey, catching the gendered language with frustration as it escapes my mouth. Why can't I stop calling every group of students "guys?"

"I'm not sure," she admits, but that doesn't dim her enthusiasm as she claims the role of memo writer and snaps a couple of pictures with her cellphone.

I move closer to the actual bike where my target already has the handlebars off and is explaining to another student, Mateo I think, how the pieces connecting the stem to the front tube move when the handlebars turn. Standing next to the student who clearly knows his way around a bike I ask, "What kind of tool is that?"

The student stares blankly at me for a moment. He isn't staring because he doesn't know the answer though, he's staring because he doesn't understand why I'm asking the question. Backtracking I smile and give the student my standard greeting, "Hi, I'm Bethany, I'm a researcher exploring learning in makerspaces. Do you mind if I observe the work you're doing?"

"Oh, no, that's cool. I'm Michael." Michael. I add the name to my notebook page.

"You seem to know your way around a bicycle, Michael."

"I've been working on bikes since I was a kid. My whole family, we're very into riding."

Michael turns his attention back to the bicycle and his other audience member, Mateo, who listens contentedly while Michael shares his knowledge of dismantling bicycles.

I move on to see what Cody is up to. Cody introduced himself to me the first week of class. I wonder if he talks to me in class because he's interested in my work, or disinterested in his own. He's not bored today though. I can see before I even get to his team's bike that he's taken the lead with the breakdown. He seems to be struggling to remove a stem from the head tube. He turns the bike sideways and instructs a team member to pull the opposite direction as him. That isn't what they were told to do but

under Cody's self-assured leadership the two start tugging in opposite directions. The bike expert sees this show and comes over to explain again what they need to do. Stepping out of the experts way, I move back towards Olivia's team.

Olivia's team seems to be struggling with the head tube also. Two young men are examining the bike in front of them. Olivia appears to be trying to move in closer to the part under consideration. "I'm pretty sure I can get it," Olivia says as she moves from standing on the left of the other two, to the right.

They don't move from in front of the work.

"I think I know what needs to be done."

They don't seem to hear.

Another member, who had been taking some notes for the memo, offers a suggestion. The other two, who are blocking Olivia's access to the bike, look up for the first time and consider what he has to say.

Olivia let's out a low frustrated growl and turns to the only person currently listening to her, me. "I like to get my hands dirty."

I listen to her tell me about the projects she's worked on back at home with her dad. Her dad always made sure she knew that she had just as much right to be in the shop as anyone else.

While we're talking, the bike expert calls the students to gather around for some more demonstration and explanation. Everyone moves towards the expert, except Jacob and his team who seem to be having a dispute over who should be recording their work in a memo.

"We have a schedule and it's not my week," Jacob states crossing his arms.

"Well whose week is it?"

"I think it's Doyle's," the third team member offers.

"Doyle isn't here," the one who has stepped up to assign a memo-writer stares Jacob down.

"Fine, I'll write it, but Doyle has to make up the two memos he's missed," Jacob responds sourly to the stare. For the other two group members, the issue appears settled, but as Jacob moves closer to the bike expert, he maintains a surly expression.

Presentation of Narrative and Interpretations

"[*B*]*egin fieldwork*, write *fieldnotes*, and then use the fieldnotes to *construct a story*"—this progression is embedded in ethnography (Goodall, 2000, p. 84). In the explanation of methods above, I explained how fieldnotes were gathered from experiences and interactions in the field site. Fieldnotes are not a story, they are only partial reflections of interpretations (Goodall, 2000). Even when they are expanded upon to make solid observations worthy of analysis, they are still not a story. When I say in the bit of narrative at the beginning of this chapter that I saw a story, the observations themselves were not that story. Like an artist seeing a sculpture in a slab of rock or an engineering student seeing a bicycle in so many pieces of steel, what I saw in those observations was the possibility of a story. I have made my best attempt to reveal that story to you in the chapters that follow.

Chapter Three: Exposition

The Beginnings: Fall 2018

"What do you think it means to be an engineer?" the professor asks the sophomore class.

It's the first week of the Fall semester and the students have already settled themselves around tables when I meekly make my way to the first open seat I see. Everything is new and unfamiliar to me, ethnography, the engineering program, graduate school, and even this campus. I had clumsily made my way into this classroom, late, after wandering the halls unsure where I was supposed to be until I was spotted by another professor.

"On your table are pieces of paper, write or draw what you think it means to be an engineer. Then we'll share our ideas with the rest of the class."

The students at the table with me reach into the center and each grab one of the note cards. There are four other students around this table, one woman engineering student, and the rest men. I'm being observant. Of what, I'm not exactly sure.

The students write on their cards, some look up and out at nothing as they brainstorm ideas, others begin doodling away immediately. The atmosphere is relaxed and as students work a few quiet conversations take place.

"Are you in Materials this semester?" one of the students I am sitting near asks another.

"I was supposed to, but there's a problem with..." The student trails off as they glance at me out of the corner of their eye. They have no idea who I am or why I am here.

Dressed casually like a student, the age of a professor, and not someone they've seen before.

"Hi, don't mind me, I'm a researcher, I'm just observing."

The unsure student seems to relax now that he knows why I'm there but doesn't bother finishing his explanation to the other student.

"A researcher, that's cool. Whadya researching?" Across the table, a young man has completed whatever doodling he was going to do and takes an opportunity to chat.

"I'm on a team exploring how learning happens in makerspaces. My role is to follow the sophomores through the sophomore design project."

"For the whole year?"

"Yup."

"Whoa, what are you going to do with all that research?"

"Write it down?"

"Are you going to write about me?"

"Uh, I might, well if I do, I'll use a pseudonym, so no one knows I'm talking about you."

"Haha, alright, can I pick my name? Call me, Cody."

"Uh, okay, Cody it is."

Before Cody has a chance to ask any more questions the professor calls the students back to attention with some instructions. "Tell us your name and what you wrote on your card. Let's start at the table in the back."

The young lady at the table I'm sitting at takes her cue and stands.

"I'm Sara, I drew a lightbulb and some gears to signify realized ideas."

Next to her, another student stands, "Um, I'm Jacob. I drew some math and science symbols because engineering is about problem-solving."

Cody stands next, "I'm Cody, nice to meet ya, I drew my truck." The class laughs and it seems clear from Cody's grin that this was the intended outcome. Cody beams and turns his card to face the class. "You might not be able to tell from there, but under the hood of this beaut is a lot of engineering."

I chuckle along with the class; these students are great. I think I'm going to like spending time with them. I hope I don't scare them away though. I better be careful not to overstep. As the students continue sharing their ideas, I hear engineering described as collaboration, giving something back, finding solutions, limitless possibilities, helping people, mechanics, and creativity.

"Okay, now tell me what design is," the professor prompts. The class bounces some ideas back and forth.

"It's bringing ideas to life."

"Nah, that definition is too "rainbows.""

Another student interrupts, "It's an iterative and human-centered process to fulfill a purpose."

"Good." The professor seems pleased with the conversation and goes on to explain to the class, "Engineering design is about asking questions, identifying pain-points, and systematically working towards appropriate solutions. It is process driven, but also nonlinear. Human centered design and design thinking are not the same thing, but you'll be using both, and both are part of engineering design."

As the professor speaks, the students listen. A few have notebooks out in which they could be taking notes, but nothing has been said that has triggered their presumed need to write anything down. Maybe they already know this from the work they did last year, or maybe they don't need to know this. The professor goes on to explain what they can expect from the class this semester. I sit up and hold my pen at the ready. I need to make note of when I should be observing the students to see how learning happens in makerspaces.

"The first semester is dedicated to conceptual design. You'll be building a toolbox of design techniques that are meant to add clarity and aid in decision making." This doesn't give me the information I was looking for, but I jot down some notes anyway.

"What tools do you know?' the professor asks.

On the far side of the room, someone suggests "Matlab."

"Solidworks?" another student suggests. Both of those, I learn, are software the students use in their courses for analysis and design.

After a pause, Sara adds, "We use the fablab." Fablab is short for fabrication lab, It's the space downstairs with a bunch of woodworking power tools as well as where the welder is. The professor chimes back in once it seems the students have run out of design tools to talk about. "Yes, good, this semester we'll be adding tools for concept generation, concept selection, project planning and more."

Cody curls his lip, "I thought the professor was talking about 'tools', tools."

* * *

"In our field, if you get it wrong, people die."

"Well that's not something that has ever been said to a student of Communication," I think to myself as I jot the professor's comment to the sophomores in my notebook. I'm sitting at one of the tables in the back of the room as the class is led through a number of activities considering the ethical implications of designing for a client. Seated at the table with me are four young men. This is a class section I haven't visited before, so I don't know the students I'm sitting with today. I've become accustomed to announcing myself and what I'm doing whenever I sit down with students, and they seem nonplussed at my presence. I note that one of the students at the table is wearing a button up shirt, suit jacket, and tie. Fancy.

"Let's take a break from ethics for a bit," the professor tells the students, "we have a video to watch." The professor goes on to explain that it's a video of the client, who they will be meeting in person next week. The students perk up; anything that comes up in this video might give them important information they'll need when designing a human-powered vehicle for their client. The professor primes the students to watch for how the client's body moves, what their limitations and strengths are, and how those things will impact the design for a human powered vehicle. The video shows the client on numerous strength training equipment in the university's recreation center.

"Look, their right foot turns outward, do you think we'll need different pedals on the bike?" one of the students I'm sitting with says to another.

"Huh, maybe."

It's early in the semester but already many of the students have been throwing out design ideas for their project. After the video, the professor explains that the class will continue discussing ethics, this time with the client in mind, and begins passing out a

handout. The lull between activities gave me some time to chat with the students at the table.

Starting with the well-dressed student I ask, "You look sharp, is there something special happening today?"

"I'm going to the career fair later. I don't need a job or anything, I'm just checking it out."

I want to find out more about why this student needed to dress up when they're just going to "check it out," but my eye is drawn to another student, seated to the right of the well-dressed sophomore. As 'suit and tie' spoke about the career fair, this other student rolled their eyes. What is the look on their face? Disgust? Hurt?

"Are you going to the career fair today too?" I ask him.

"Me? No, I have classes and work all day today. But I shouldn't be doing any of those things today either."

"What should you be doing today?"

"I should be with my family observing Yom Kippur. If this were a Christian holiday, I wouldn't have to be here because none of us would be here. And they certainly wouldn't have planned a career fair," he states with clear disdain.

"Oh, I'm sorry. What would you be doing if you were home?"

"I'd get to see my grandmother who only visits on holidays. I'd get to hear my sister sing at service." Describing the events that he's missing out on by being here, the students voice softens from bitterness to sorrowful longing. "I never appreciated these traditions enough as a child. Oh, and the break fast meal, you've never had a meal like it!"

The student's description of the meal at the end of Yom Kippur is interrupted by the professor calling everyone's attention back up front. As the professor moves the class on to the next task, I make note of the Jewish student. He has a Star of David necklace hanging on the outside of his shirt, a quiet announcement to others that there is somewhere else he should be today. He should be listening to his sister singing at Temple, not listening to the professor explain, again, the importance of public safety.

* * *

"A persona is a description of a typical person in a group. It's like, if I was designing a new kind of smart assisted-living space, I would say: my client is Joe, he's 68 and a recent widower. It's the kind of person you would expect to use your product." Sara kindly takes some time to explain to me the definition of persona.

It's a cool Tuesday morning on campus, and in today's class the students are going to meet their client in person for the first time. First, they are learning about skeletons, a collection of information about their client or target population, and personas, which Sara explained to me is a sort of composite character based on that information. The students just finished creating a persona for a sophomore engineering student in small groups at each table. Now, as most people have wrapped up their discussion, conversations pop up around the room. I'm sitting with Sara, Hailey, and Jacob today. I like coming to this section because the students are familiar enough with me that they seem comfortable with my presence and don't mind sharing with me about the work they are doing.

"I think maple syrup makes blueberry pancakes taste weird." Hailey's conversation with Jacob catches my attention. It's one of many random discussions that might pop up in the space between activities.

"No," Jacob replies, "it doesn't matter what kind of pancake it is – maple syrup is the only real syrup."

"We use agave syrup at my house," I volunteer. Jacob cringes.

"For some reason, I really don't like pancakes, but I like waffles," Sara is the last person at the table to join the conversation.

Before Jacob has a chance to lecture Sara about pancakes, it's time to share the personas with the rest of the class. "Each table tell us about your client," the professor instructs.

The students take turns, table by table, describing what they came up with. A student at the table in front of us stands, "our client is James, he's in his second year of engineering studies and he is tired and hungry." The class chuckles but the student continues, "James spends so much time on homework and extra-curriculars that he doesn't have much time for anything else. James' goal is to get more food and more sleep."

After the description of James, Hailey stands up to address the class. "Our client is Leah, she is a hard-working sophomore engineer. She is stressed out because she has so much to keep up with. Her goal is to find a way to be happy but still get good grades," Hailey wraps up the brief persona presentation for her table flashing a smile at the professor and the rest of the class before sitting back down.

The next student stands, "This is Peter. As a sophomore engineer, Peter has a very demanding schedule. Like all his friends, Peter takes at least 18 credits a semester, sometimes more."

Another student in the room stands to speak for their table, "Jackie is a sophomore engineering student who is very concerned about her grades. Her classes are hard and the grading is tough. If Jackie gets below a 'C' she will have to be a fifth-year student and that's something she can't afford."

As the students speak, I jot the trends in their descriptions down in my notebook, "demanding schedule, stressed, tired."

The professor moves the students on quickly after they've all had a turn to describe the persona of a sophomore student. It is almost time for the client to arrive. "Don't forget!" the professor impresses on the students a summary of the previous week's class on listening and asking questions, "ask powerful questions, ask open-ended questions, and then LISTEN, don't answer for the client!"

As the professor reminds the students the expectations for how they should interact with the client, they arrive, getting assistance into the studio from a couple of the students near the door. The client isn't shy introducing themselves and seems genuinely excited to be working with the students. They give a brief description of themselves and the limitations that make it difficult to ride a traditional bicycle. Then they turn it over to the students for their questions.

"How do you like a recumbent bike?"

"Have you ridden a two-wheel bike before?"

"How low can you sit and get up on your own?"

One of my graduate classes this semester is qualitative research methods, a class I need to take as part of the training I get to do research, which includes how to ask good questions. I recognize that these are not the open-ended questions the professor was encouraging the students to ask. The first questions that the students ask are specific and it becomes clear that the students who were first to speak up did so because they have design ideas in their mind already and are trying to find out if those ideas are going to work. However, as the questions keep coming, they become more open-ended.

"What do you enjoy about being outside?"

"How do you like to spend time with your family?"

"What are your goals?"

* * *

"And that's why the client wants a human-powered vehicle," the student wraps up his persona presentation. At this point in the semester the students were introduced to the client through a video, met the client in person in class, and were supposed to have at least one person from their team meet with them outside of class to ask more questions, get more information. With that information, they were to create a poster-sized persona of their client. These posters included direct quotes from the client, strengths, challenges, goals, and more. Unlike the personas Sara described, these are not about a created person meant to represent a typical user but are specific to the actual client for this project. The presentations of these personas were considerably more in depth than the brief exercise the students did in class to describe Sophomore students as a client. Based on what I knew about personas from the previous class, it seems like they all completed the

assignment well. These posters will hang in the bike lab where the students will create the product for the client.

"How appropriate," I think "what a neat way to stay focused on the client."

The professor, who had offered little feedback during the presentations, now circled the room looking over the posters again. After several quiet moments of looking over the posters the professor asked, "Who went to visit the client?" Only a handful of students raise their hands but only one person from each team needed to. The professor directs the next question at the students who spoke with the client one on one. "What were your takeaways from your time with the client?"

"The client is a really friendly person."

"They help a lot of other people."

"Yeah, they'll go out of their way to help people, however they can."

"They were super nice, they're excited about this project, it made me feel good to hear how much what we were doing meant to the client."

"Mmhmm," the professor nods. "What should the persona do?"

Crickets.

"How should I react to the persona?"

More crickets. "What's happening here?" I wonder to myself. I saw the persona presentations in another section and that professor did just what I would have, gave a thumbs up and moved on.

"Who captured the client's friendliness? Who captured how the client helps people?" Pause. "Who captured the client's excitement about this project?" The students exchange uneasy glances at each other. "A persona should inspire an emotional response,

but I feel nothing looking at these. It should embody who that person is, but these do not. These are not personas, they are skeletons. Every team in here has to redo their persona or you will get a zero."

I'm shocked. I write in my notebook, "holy plot twist Batman, the professor is making them redo the entire assignment!"

The professor adds, "you'll have to do this assignment on top of the other homework that was assigned for this week."

I glance around the room to try and gauge the students reactions. I know I would be angry in their shoes. Some people look deflated at the news, others annoyed. I spend the rest of the class looking for an opportunity to ask the students how they feel but the professor moves rapidly from talking about personas to stakeholders, specifications, and more. It isn't until the end of class that I have my opportunity. As students are gathering their things to leave class I ask a student nearby how they felt about redoing doing the assignment.

"We're relieved!"

"Relieved?" I ask, surprised.

"Yeah, we only started ours a half hour before class, so now we have a second chance! Phew."

Huh. Looking at their persona, I can see that it does look more like a large sheet of paper with bits of information scrawled across it than some of the other put-together looking posters around the room. I ask someone else getting ready to walk out the door, "are you glad to have another chance to do your persona?"

"What?? No! We worked really hard on that. I have so much homework this week, I do not have time to do this over!"

I write in my notebook, "responses are mixed."

When I raise my eyes from my notebook, only one team is left in the room. They are chatting with the professor over at their persona. The professor points out, "look at the picture you used, it's the same one everyone else lifted from the internet, the client in a button up and tie. Is that the client?" The students, with dawning understanding, shake their heads. The professor continues, "You told me all the stuff the client does for others, show me that." And section by section the professor clarifies what a persona should be. This team didn't know what they needed to do to make it better, so they asked.

* * *

"So that's how you create a Pugh chart," the professor turns around to the students who are looking back rather blankly. "What is your muddiest point?" the professor asks the class to encourage them to asks questions and make sure they actually understand what's been explained. No one asks a question, but the silence isn't reassuring.

"Next week is bike breakdown. Don't forget your safety glasses." The professor tells the class before dismissing them. "Everyone knows to always have your safety glasses, right?" The students file out. As always, a couple linger to talk to the professor but soon they are gone too.

"Do you think the class grasped that bit about Pugh charts?" I ask the professor when everyone else has left.

"Well, they have to do one for their homework this week, so they'll figure it out," the professor adds, "or they won't."

I follow-up with, "Are Pugh charts going to be important for the final design? or …" I dig around in my head for the name of the other design tool they learned about today, "Morph Matrixes?"

The professor laughs, "No."

In confusion I wait for more explanation.

"A morph matrix is silly but being able to combine concepts is very useful. The specific techniques aren't all that important, learning to blend concepts, learning to make the right design choices for the project, that is important."

* * *

"Am I right to assume that everyone here is either in or has already taken Statics and Dynamics?" the professor asks diving into some problems. I'm sitting at a table with four students, but I only know two of them. Most people seem to know Alexis, she's involved in many of things that go on inside and outside of the classroom. Mason is sitting next to her; he tends to stick to himself and I only picked up his name when the professor used it. As the professor speaks and writes on the dry erase glass boards up front, I try to follow along but "FBD" is well outside my comfort zone.

"What's an FBD?" I whisper to Alexis.

"It's a free body diagram."

"Free body diagram," I jot in my notes along with some sketches from the board, numbers, variables, symbols that hold little meaning to me. It reminds me of the time I watched novellas in Bolivia with my bilingual friend. I only understood some of the

words and thought that I was actually keeping up with the plot based on the little that I knew. But when I asked her to confirm, I realized I had no idea. Some of the work on the board seems like something I could work out, but I try my hand at a few of the problems and it does not go well. Instead, I write everything down, maybe it will make more sense later.

Alexis doesn't seem to be struggling with the work at all. I check on Mason and notice with surprise and instant curiosity that the back of Mason's calculator has a large MAGA logo on it. He sees me looking at it and shifts in his seat.

"Where did you get your sticker?" I ask carefully, trying not to reveal my own displeasure with the current administration and their infamous logo.

"I made it. I printed it downstairs."

"Oh!" I realize that when Mason says downstairs he is referring to the makerspace that the students think of first when you ask about makerspaces. All of the spaces are technically classified makerspaces, but some are more associated with fabrication, and that one in particular is a "makery" like the others in the campus libraries with 3d printers, vinyl cutters, and more. This makery is just for the engineering students though; they are the only ones with "swipe access" to it.

"Do you spend much time down there?" I ask Mason.

"Yeah, I waste a lot time in there."

Another problem goes up on the board and Mason turns his attention back to task at hand. Mason is polite but doesn't seem particularly interested in chatting with me so I back off and look at the problem the students are working on instead. The objective is to

find the force on "e," but Mason appears to be struggling. He turns to a young man on right and asks, "I'm kinda lost, what are you doing?"

The student replies "trying to find the force on e."

Mason is momentarily taken aback by the least helpful reply ever but tries again, "how are you figuring out positive and negative?"

Alexis, who has already finished the problem interrupts the conversation that is going nowhere, "you have to think through the line of action." Going on to explain further, Alexis manages to help Mason work himself out of the hole until he is able to proceed on his own. The professor, who is making rounds, stops at our table and reminds the two students who are still struggling that "it's all about the line of action."

I can't help but laugh when Alexis raises an eyebrow at me with a self-satisfied nod.

* * *

I'm sitting with a section of sophomore students for their last class before the final exam next week. During this semester, the students learned about communicating with stakeholders, identifying and defining the problem, developing specifications for the solution to that problem, and generating designs to meet those specifications. At the end of the semester, each team of 4 had a design that could be prototyped but as I've heard before these designs, or at least not all of them, will be prototyped because next semester the students are regrouped into larger teams.

"Cough, cough," Alexis is across from me at the table and this is the third time she's started coughing in class.

"Are you okay?" I ask with increasing discomfort at the number of students I hear sniffling, sneezing, and coughing around the room.

"Oh, I'm sick."

"Should you be here?"

"I can't afford to miss any classes. It doesn't really matter, everyone else is sick too."

Great. I'm going to take a bath in hand sanitizer when I leave. Two students are having a conversation next to me.

"I think it would be cool to work for Elon Musk."

"I'd rather be on the Space Force."

Germ infestation aside, this is interesting topic. "What are you talking about?"

"Just what would be a better way to get involved in space exploration."

"Elon Musk is great, he doesn't even care about the money, he's just trying to make the world a better place."

"Space Force is going to be really important. We're going to have to have a way to protect what's ours because that's how the world works. When you put different people together, they go to war."

Fascinating. This is the last time I'll see these students until after winter break, but I'm already eager to hear more from them.

Spring 2019

"Welcome back," I think to myself as the parking lots that were almost empty over winter break are quickly nearing capacity. I've got my space though, I'm just sitting in my car, waiting for nothing in particular, before I head inside to make observations in

the Tuesday morning section of Design II, the first meeting of the second half of the bike project.

The summer before this academic year, as I made arrangements to begin grad school, people would say to me, "Oh, you're going to go to grad school with two small children? Wow! That's going to be so hard." I would smile and tell them, "That's okay, I'm up for the challenge." I didn't actually think it would be that hard, I'd been going to school full-time while growing our family for several years. The first semester was an unkind surprise. Three weeks into the semester I came to the realization that maybe I couldn't do this, maybe this really was too much. But I stayed. At orientation, someone said that grad school was about perseverance, not perfection. "How true, how true," I muse in my car as I reflect on my efforts just to hang on. I made it through the first semester though. So why do I feel even more anxious at the beginning of this new semester than I did then? Why do I feel like I have even less of a handle on everything now than I did before? No time to figure it out now though, I tell myself as I reluctantly gather my things and head inside. At least I get to hang out with the sophomores today. I'll have a lot to do this semester, but hanging out with the sophomores is the highlight of my week.

Heading into the familiar studio, I see some faces I recognize and some I do not. Students select sections because they want a particular professor, because there is only one that fits their schedule, because their best friend is in this section too, or perhaps because they learned the hard way that morning sections are a bad idea for them. Whatever the reason, the students in this section of Design II are a mixture of students from all the different sections of Design I. Among other things, this means there is a

cross-pollination of ideas for designing the client's human-powered vehicle. It also means that students will be regrouped into teams and may have to let go of some of their preferred designs in favor of more popular choices. I find a seat at the table nearest the door between Alexis and Mateo.

The professor begins class with a recap of the design process up until this point and an explanation of what is to come. Following some lecture and PowerPoint slides, the part of the class the students have been eagerly anticipating comes. It's time to group the students into the teams they will be on for the remainder of the project. The professor tells the students to brainstorm what types of roles they will need on their team. Students offered some standard roles, such as Project Manager to keep everyone moving in the right direction and Recorder to keep track of the work being done. The professor tells the students to keep going, "what else?"

Cody pipes up with "out-of-the-box thinker," to the chuckles of some of the other students, but the professor adds the suggestion to the board.

Looking for some particular roles the students hadn't mentioned yet the professor asks, "what about someone to oversee calculations?"

Sara offers, "analyst?" and it is added to the board.

The professor continues probing students until they also add fabricator to the sizable list of roles. "Now," the professor leads, "some of these roles are probably redundant. Organizer and Scheduler, these sound like the same role. Which of these roles should be collapsed to make the roles distinguishable?"

The students combine Team Leader with Project Manager, and Materials Specialist with Researcher. As they work through the roles, there is discussion among the

students to elaborate what the roles do. “The communicator isn’t the voice of the team. They’re the one who has to meet with the client and present ideas and bring feedback back to the group. That needs to be its own role.”

The professor listens to the student’s discussion and rearranges the roles listed on the dry erase board up front as needed. At the end of this process, there are eight job titles spaced out across the board: Project Manager, Communicator, Recorder, Researcher, Safety Supervisor, CAD Expert, Fabricator, and Analyst. Satisfied that the students have reached the end of this process the professor reminds the students that being assigned to a role doesn’t mean you are the one who does all the work related to that role. It means that you are the one overseeing that work and making sure it gets done.

As the professor explains this, they drop stacks of post-it notes on the tables in front of the students going on to tell them “take three notes, put your name on each one, then number the notes 1-3.” The students don’t wait for the professor to finish explaining the process that is happening before grabbing notes and writing their names on them. It seems, I am the only person in the room that has no idea what is happening. “Put the sticky note with the number one under the role that is your first choice, the number two under your second choice,” the professor continues as I figure out what is going on around me.

Alexis rises from the table and confidently places her first post-it under “Project Manager,” before placing the others elsewhere on the board.

“I see you placed your first note under project manager.”

“I’ve been project manager for two different projects already,” Alexis explains confidently. Watching the other students place their notes, I notice that Project Manager

is a popular role with the most number one notes under it. Communicator has the most notes overall, but fewer indicating that this is a first choice. The least populated roles are CAD Expert, Researcher, and Recorder. In the Recorder and Researcher roles, only one person indicated that this role was their first choice.

There are two professors teaching three sections of Design II and both are present for this part of the class period. One of the professors is new, I suspect the presence of the other professor is to make sure common pitfalls in grouping students are avoided but they never actually explain why it takes two of them to select teams. Perhaps it's just to acquaint the new professor with a process that could easily become overwhelming. After all the notes are placed, the professors move back in forth in front of the board. They sort the number one notes from the others and move right into grabbing notes from one place, moving them to another. Their hands are holding an assortment of notes with students' names as they place them here, grab them again, move them there. They stop in front of the board for quick, whispered conferences and begin moving notes again. At the end of it, they are holding three stacks of notes.

There are twenty-four students in this section, now divided into three teams. "The project managers are Alexis, Peter, and Lauren," the professor announces, "Stand up, you three." I see Alexis had every reason to feel confident that she would be selected to manage a team. The professor then reads out the names of the students on each team. As names are read, the students collect their belongings and join the Project Manager. I watch as Mateo, Hailey, Jacob, Mason, Sara, Doyle, and Cody gather their stuff and loosely gather around Alexis. Once everyone is grouped with their respective teams, the

professor directs them to the bike lab telling them to take some time to get to know their teams and giving them a few tasks to accomplish.

I decide to follow Alexis and the others on this team. The group circles around a tall table in the bike lab. There are stools but no one bothers with them. Alexis is at the head of one side of the table. I find a spot to stand at the opposite end next to Doyle. "Does anyone mind if I hang out here and observe?" I ask the group before any tasks get underway. Being careful to look at each member of the group, so I don't miss any verbal or nonverbal indicators of discomfort at my presence, I am met with a series of welcoming smiles or indifferent shrugs.

"Is everyone okay with that?" Alexis double-checks with group. When no one objects, Alexis takes the stack of sticky notes handed to her by the professor and looks them over to see what roles everyone is in. The first note in the stack is Alexis's and it has been marked with a large M in black, Sharpie marker. M for Manager. However, none of the other notes have been marked.

"No matter," Alexis leads, "Mason, this is your number one note, what role was your first choice."

"Project Manager," Mason raises his eyebrows dispassionately.

"Well that's not going to work," Alexis says as the team realizes that following the professors' dance with the sticky notes up front, the numbers no longer bear any meaning. Jacob takes the initiative and goes to a nearby dry erase board.

"What were the roles?" Jacob asks noting that they can sort it out easily once everyone shares what they signed up for. Jacob writes "project manager" on the board and writes Alexis' name next to it. Below that he writes communicator and notes out loud

"this was the role I chose," as he writes his name next to it before anyone has a chance to debate it. "What else?" Jacob asks the team for the other roles. They are able to name some, but I'm the only one who wrote them all down so I hand a list to Jacob who finishes writing them on the board. Going down through the list, students pipe up when the role mentioned was one they had put sticky notes on. Three different people in the group had put project manager as their number one choice so now they considered their second and third choices as they sorted out who was going to be in charge of what.

"Fabricator?" Jacob asks wielding the dry erase marker as Alexis watches on quietly.

"Oh, that's me." Cody tells Jacob. Jacob adds Cody's name to the board.

"Safety Supervisor?"

"Me," Doyle and Mason say at the same time.

"It was my number two choice," Doyle tells Mason.

"It was my third choice, but both of my other choices are already filled," Mason answers back. Neither of them seem terribly concerned about how this is playing out, but I note with interest that the way Jacob has stepped in to help sort things out is going to leave some people in roles that weren't any of their three choices.

Alexis has heard enough and speaks up, "It doesn't matter, everyone helps with every part anyway." Mason and Doyle nod in agreement. I note that Alexis doesn't mind stepping back while other people sort things out but that she will come right back in when needed.

"Right, it doesn't matter," Doyle repeats, adding breezily to Jacob, "so you can just put me down for 'Safety Super.'"

When it's all said and done, Hailey is the researcher, Sara the analyst, and Mateo the CAD expert. That only leaves the role of recorder and Mason left to be paired together. Not any of his three choices, not something he seems keen on in any way.

I feel disappointed for him leaning towards him to say, "that stinks."

He responds telling me, "it's okay, the work is shared, having the role just means you have to make sure it's getting done" but he expresses a complete lack of enthusiasm with how it turned out.

"When can everyone meet?" Alexis moves the conversation to picking out a regular meeting time. Some people throw out times they can meet, other people throw out times they cannot meet. I'm writing notes as the students discuss but I am already lost. "Okay, stop," Alexis tells the crowd. Sara steps up to suggest they start a When2Meet. When2Meet is one of the many handy, free online scheduling tools I've seen students and professors alike relying on to get and stay organized. Following through with her suggestion, Sara immediately goes to the website and selects a list of possible times and sends the generated code to everyone else so they can indicate which of the times works for them. All of this is done on the students' smartphones.

I watch on as Cody starts talking up the "swivel seat" idea he came up with last semester, but as soon as Alexis mentions that a swivel seat reduces stability and doesn't add much functionally it's pretty clear that the group as a whole isn't ready to think through this problem.

"That seems like something we should figure out when we meet on Friday," Mason suggests.

The others nod. I don't know that they'll be any more ready to tackle the problem on Friday, but at least they can stop thinking about it for the time being. "Okay, we need to submit a memo with our team name on it. Let's pick a name and be done for today."

"How about Team Rocket Blasters?" a widely grinning Cody suggests. "I like it," Mason shrugs.

"No," says Sara, "that has nothing to do with our client. This should be about the client." Everyone pauses at this in quiet contemplation.

Hailey's eyes scan the posters still hanging in the bike lab from the first semester. Drawing from a quote from the client in bold letters across the top of the nearest poster, Hailey is the first to break the silence, "How about, Team Up & Down?"

Following her gaze to one of the posters on the wall, I see a quote from the client that one of the teams from last semester put in bold print across the top of their persona, "Life is full of ups and downs." The team members nod and glance around at each other.

"Team Up & Down it is," Alexis states satisfied and dismisses the group until their next meeting. I learn the settled upon meeting time is Saturday. I'm not on campus on weekends; it dawns on me that now that as action moves out of the regularly scheduled class period it may be trickier for me to capture.

I'm curious about Mateo, he was in the section I attended most often during the fall semester, but I never sat at the same table as him. If he ever piped up to answer a question posed to the entire class, I certainly never saw it. Taking the opportunity as he gathers his notebook into his bag, I approach him. "Hi, so CAD Expert? Do you like CAD, CADding, doing CAD stuffff?" I awkwardly trip over the acronym I've heard since day one in the engineering department but haven't taken the time to ask about.

CAD, for the uninitiated, stands for Computer-Aided Design. After the students create sketches and mock-ups of what they hope to build, they will also need to create a model using CAD software, such as the one used in this department, Solidworks. They can use these models to manufacture their own unique parts and run analytic tests on their human-powered vehicle. For example, the CAD model can tell the students before they even order parts if the design they made will bend out of shape when the client sits on it. From the student's descriptions, Solidworks, and perhaps CAD in general, is notoriously tricky and fraught with more ways to get it wrong than right.

Mateo offers me a generous smile. "Yeah, I used CAD software a lot in high school. I went to a STEM high school and everyone there was pretty well trained in it."

"I wonder why so few people wanted that job," I ponder aloud to Mateo.

"Oh, well, it can be pretty tough. I've been using it for a while, but it's still tricky for me." Mateo's face brightens for a moment and he reaches into his bag and starts rummaging around. From somewhere in the depths of his bag, he pulls out a sort of rectangular, cuboid.

"I made this for my phone, to prop it up. I wanted to work on overlaying 2d shapes onto 3d primitives. That will come in handy if we decide to include the arm rests from Mason's design. I have an idea for a custom pedal we could make too, I've toyed around in Solidworks designing it, but I don't know what the preliminary design will be yet, so I haven't done too much on it."

"Oh! Um, do you think the team will adopt Mason's design?"

"I'm sure everyone will contribute to the design, but Mason's really good at figuring out if something will work."

"So, CAD is used to design custom parts?"

"You can use Solidworks for that. Mostly though we'll have a full model of our design in Solidworks. We can test it. We can see what changes will do to the overall design. That stuff."

I feel ashamed for assuming that because Mateo didn't say much, he didn't have much to say. He's quiet, even as we chat together now, I find myself softening my often-loud voice to match his soft and hesitating tone. Some of the students don't seem to understand enough of what's happening at this point to be able to explain it, but he does. Mateo will be a strong asset to his team.

"Are you excited about this semester?"

"Yeah, I think it's going to be more interesting. Last semester was important, but it was all in our heads. Now it will be in our hands."

Chapter Four: Action

Mid-spring Semester

It's not quite warm, but the bitter winds of winter have long since given way to chilly but mild breezes and bright sunshine making the morning walk to the engineering building increasingly tolerable. After dropping off my things in "my office," I head to the studio where I know the Sophomores will be gathered for class. From my vantage point, not a lot has changed from the previous semester. The students compressed all of the activities of the previous semester into the first two weeks of this one as they generated a final design. Lately they've been working through calculations to determine things like force analysis, center of mass, and other such considerations in designing a human-powered vehicle. They're able to do that now because, even though the designs are still subject to change, each team does have a working design to which to apply these analyses. As I near the room, I am joined in the hall by a student carrying an awkward structure of wooden 2x4s. Peering over a 2x4 I see a familiar face.

"Sara, my goodness! Do you need a hand?"

"No, I've got it. Actually, could you get the door for me?"

"Of course," I answer walking ahead to open the door wide for her, "what is that?"

"It's the proof of concept for my subteam," Sara replies only slightly out of breath from hauling whatever this is to class. I follow her to the studio and notice with excitement that throughout the room there are multiple, similar oddities. On one table sits an assemblage of k'nex. Leaning against the wall behind one student is a bicycle wheel attached to a PVC pipe pole. Sticking out from under the table near the door are two

gears mounted on a board with a length of chain running between them. Fascinating assortments of bicycle parts, wood, tubes, and toys are scattered throughout the room.

The professor begins class the way I've seen them do a couple times before. They roll a chair to the front of the room, sit eye-level with the students, and ask them how they're doing. Around the room a few students indicate that they're okay. "If you're looking ahead, you should be panicking," the professor tells them, which is why they've taken the time to check in on them. Moving on, the professor talks for a bit about transitioning to detailed designs before taking a seat at one of the tables in the room and inviting any one of the teams to begin the presentations. The students glance around momentarily before Alexis rises reaching for a contraption of bicycle handlebars and pipe. Following their project manager's lead, the rest of Team Up & Down collects their creations, three in all, and gathers in front of the class.

Alexis sits a laptop on the lectern and plugs in an HDMI cable which shows a CAD model of their human-powered vehicle to the rest of the class. From the 3d image being projected onto the screen, we can see that their bicycle has three wheels, two in the back, and a bucket-style seat. Most of the teams have settled on a three-wheeled design but that doesn't stop anyone from referring to the human-powered vehicles as bikes or bicycles. Alexis briefly explains the overall design before transitioning to a description of the first proof of concept. "Our subteams reflect the parts of our human-powered vehicle that are custom-made. Our design uses a custom frame, seat, and propulsion system," Alexis explains to the class.

"Everything else is off the shelf?" the professor asks.

"Um, we will probably have to make custom pedals, or modify pedals."

"Probably?"

"We don't know yet."

"Well you should probably figure that out," the professor says before letting Alexis continue the presentation.

This style of inquisition is popular in the engineering department. Some students tell me they don't mind, that the professors are preparing them for what it's like "out there," or that the professors are hard on them because they care. Other students bottle up resentment over these interactions during presentations, but will let it out as soon as the professor is out of earshot. Alexis may not have been expecting questions so quickly into the presentation, but is unfazed and moves into an explanation of their proof of concept.

"We're the propulsion subteam," Alexis says pointing to Mateo and Jacob, "and our proof of concept is the crank for the upper propulsion system that ties into steering." Alexis explains that instead of traditional handlebars controlling steering, the client will be cranking the "handlebars" which propels the bicycle forward, while also twisting the upper propulsion system left and right to steer. The proof of concept they built has a piece in the center that looks like a "T," the bottom turns left and right like steering on a bicycle. From either side extends crank shaped arms that rotate forward.

With a nod from Alexis, Jacob continues the presentation, "We met with the client to see if they felt comfortable with the forward rotation and left-right steering together. We also checked hand position and arm extension to see what was comfortable."

The professor's head cocks to one side.

"Uh-oh," I think, I don't know where they went wrong, but we're about to find out.

"How did you test hand position?" the professor asks. Jacob explains that the "grips" on their proof of concept can move in towards the center or out and they marked the distance apart that the client felt most comfortable with. How far in front of the client the whole set-up should be got a bit murkier. The test included Jacob holding the contraption and moving it up and down and closer and further from the client.

"That's how we figured out how high it should be," Jacob finished the explanation.

"How high up from what?" the professor responded, "and what were you measuring the distance from when you determined how far in front of the client it should be?"

"We tested where it would be comfortable to have it when the client is seated like they will be riding our bike. So, we had them sit down and I held it in front of them."

"So you just held in three space?"

"Then we measured."

"What did you measure?"

Alexis stepped in to help clarify and give the professor the information they were unsuccessfully trying to pull from Jacob. "We measured the distance from the ground and from the back of the seat."

"What seat?" the professors adds, "who's on the seating subteam?"

Sara, Doyle, and Hailey raise their hands.

"Does your seat have a backrest?'

The three members of the seating subteam nod.

"What's the angle of the back rest?"

Hailey and Doyle look at Sara who replies, "we didn't, we haven't determined that yet."

"What is all that?" the professor asks gesturing to the wooden structure Sara carried in with her today. Sara explains that their design includes a swiveling seat to make it easier for the client to get on and off the bicycle. The structure, I can now see as Sara explains it, is roughly a chair with metal plates and parts where the top half and bottom half meet. Apparently, they had tried to construct a swivel mechanism and then have the client try it out, but it didn't go well.

"The swivel didn't work," Sara told the professor.

"Did you bring this to the client?"

"Yes."

"What information did you get from the client if you still don't know the angle of the back rest?" the professor inquired of Sara.

"We did learn something about the height of the seat."

The professor let out a long sigh, "the height of the seat from what?" Before anyone has a chance to respond, the professor blurts, "frame subteam."

Cody and Mason move front and center to provide answers about the bike's frame.

"What's your proof of concept?" the professor asks.

Cody holds up what looks like the basic frame of the bicycle they've designed made out of clay. It looks like they might have made it on their way into class today. It's

a little better than something my five-year-old might be able to make from clay, but just a little better. Cody doesn't get to talk about their proof of concept before the professor says, "that's not a proof of concept, that's a mock-up, go sit down."

"We tested it," Cody says defending their little clay creation.

The professor looks more bemused than annoyed that Cody is challenging the assertion they hadn't brought in a proof of concept. "Okay," the professor cedes, "what did you test?"

"We tested deflection by pressing down on the center." A few of the students in the room snicker. Cody grins.

"There is nothing about what you've brought in that relates in any meaningful way to your design. Go sit down." This time Cody does, he is still smiling. Mason follows behind him. Turning to the class, the professors adds, "mock-ups are helpful for communicating ideas with the client. When you sit down with a client to explain what you've designed, it's valuable to have sketches and mock-ups to show them your ideas. Presumably, you've all already had these conversations with the client and are moving forward with a client-approved design. At this point you need to be testing your design choices, that's what the proof of concept does."

"What is that?" the professor nods towards the k'nex structure.

"It's a mock-up," the builder of the k'nex frame, a quick-learning student, replies.

The professor turns back to Sara, "tell me about your test."

"Our proof of concept revealed a lot of challenges we hadn't anticipated," Sara begins. Continuing, she explains how the seat swivel mechanism was expected to work but that when the pieces came together it just, didn't.

"What did you learn about manufacturing?" the professor asks.

Sara opened her mouth to respond but before the words had a chance to escape Doyle jumped in to answer instead.

"We learned that we have to think more holistically about the mechanism, really consider how the parts are going to come together," Doyle responded eloquently. Sara's face was marked with subtle incredulity as her lips pursed and eyes narrowed on Doyle.

"We learned that having a lever here doesn't do anything once there is weight on it," Sara stated ignoring Doyle's previous remarks. Hailey is on this subteam too but hasn't had anything to add up to this point.

The professor says to the class, "analytical prototypes are useful because they're flexible, there's a lot you can figure out before you start using up your time and materials with analytical models alone." Looking at Cody the professor adds, "like deflection." Then continuing to the whole class in acknowledgment of the seating subteam's experience, "but physical prototypes are needed to show unanticipated issues." Shifting back to the propulsion subteam the professor adds, "you got some valuable information from your meeting with the client, but it means nothing if you cannot put it in the context of the rest of your model. There needs to be better communication across the subteams or this won't come together as one build." Alexis, Mateo, and Jacob simply nod.

The presentations continue with Teams Engaged and Herding Cats. Some of the proofs of concept tested how systems might be combined, others helped determine the dimensions of the final design by figuring out what positions the client is comfortable being in. Some tests required the students to meet with the client, others could be performed in one of the makerspaces. The professor's feedback included active problem

solving; with a background in mechanical engineering the professor had useful suggestions for teams whose tests revealed roadblocks they weren't sure how to get around. Among the students who met with the client, some went prepared with devices like an angle indicator, others went with their assemblages and made marks indicating distance or angle. One thing that wasn't clear to me, nor to some of the students apparently, was what tests should be conducted with an analytic model and which would benefit from a physical model.

"None of what you built was necessary, you already have all of the information you need, this could have been done in CAD," the professor tells one group.

"These are impressive calculations," the professor tells another group, "but with a wrench and five minutes of the client's time you could have figured out the same thing and saved yourself a lot of time."

Following the presentations, the professor explains to the students that they need to finalize a bill of materials, that's the master list of materials they need to build their bikes. Some of those parts need to be ordered, some of the parts will be gathered from bins of recycled parts in the bike lab, other parts may be machined in the shop downstairs. When it comes to where to find parts, the professor has many bits of advice: "Don't buy a part that might already laying around, your professors and the experts know what's on hand so ask. Don't make a part you can buy; it takes more time and the machine shop is going to have a long queue towards the end of the semester. Don't reinvent the wheel."

Spring break is fast approaching and while the students are away, the parts that have to be ordered for their bikes will arrive. "Who has obtained a locker in the bike

lab?" The students glance around at each other, but no one responds to the professor's question.

The professor continues without additional pauses, "It should take you ten minutes to complete the safety quiz and you need to do that before you team can have a locker. The parts you order are delivered to the expert and they will need a place to put them for you. Make sure you do that this week. Also, we'll be tightening up the expectations for your behavior in the bike lab. If I see you in there with drinks or without safety glasses you can expect to have your access to the bike lab revoked."

The students have a lot of little things to accomplish between now and Spring break, as well as midterms to study for. When they return from Spring break, they will have three weeks to build the alpha prototype of their bike, then two more weeks after that to complete the beta. The professor ends class with a piece of advice for the students, "Think smart. Don't think 'get the assignment done'."

At the end of class, most of the students don't go anywhere. Instead, gathered in their teams they discuss next meeting times, next steps in determining materials, and next assignments that need to be done. I wander around the room a bit to see how the teams are doing. Team Herding Cats has a lot of work to do to finalize a bill of materials. It seems there is some question still regarding the what they'll need to build the bike.

"We don't need one of those for a delta design."

"Our bike isn't delta, it's tadpole."

"Since when?"

"Since we switched to a tadpole design."

Hmm, maybe a lot of questions. Team Engaged is meeting on Saturday to finalize the bill of materials but they seem to have a pretty good grasp on what they'll need.

"Let's meet in the lab the Monday after break and grab the recycled parts from the list Michael generated."

"Sounds good."

"I'll be there."

"I'm getting ready to meet with some people from the Wednesday section to study for the midterm if anyone wants to come with me."

Team Engaged is heading out the door with a solid plan for what to do next. Team Herding Cats is also gathering their things to leave. I wonder to myself if they have a plan too. That just leaves Team Up & Down.

"How's it going?" I address the group.

"It's fine," Alexis replies, "we're just figuring out the bill of materials."

"We'd save a lot if we just bought the two bikes," Mason has moved the conversation forward despite my brief interruption.

"Fine," Alexis responds to him, "does that mean we don't need any steel tube?"

As the conversation continues over the bill of materials I turn to Hailey, "you're buying two bikes?"

"Yeah," Hailey replies, "it's going to be cheaper to buy bikes and cut them up than order the individual parts."

"Neat, how are you feeling about the project?"

"I feel good about it," Hailey says, "it's a lot, but I feel like it'll be okay."

"Good, I hope so." Tuning back into the conversation over bill of materials, it sounds like most of what they need has been decided, but Jacob is going to meet with the client one more time to figure out some dimensions before they turn the list in. As the team packs up and heads in different directions, I follow Sara out into the bike lab. She's opted to leave her large wooden structure under one of the tall tables there.

"I'm going to work on the swivel later in the week," she explains to me.

"How are you feeling about the project?"

"I don't think three weeks is enough time to build a bike. Not to complain, but the people on my subteam seem to be rowing in different directions."

"Speaking of which," I jump in the door Sara has opened, "I noticed a look on your face when Doyle answered the professor for your subteam. What was that look? Do you remember when I'm referring to? It was..."

Sara cuts me off, "Oh, I know exactly when you're talking about. He tried explaining what we learned from our failure with the swivel seat, but how would he know? He wasn't there for any of the building or testing of it! He showed up for ten minutes on Sunday and then had to go. I didn't see him again until class today."

"Wow, speaking of the swivel seat, wasn't that Cody's idea? Why isn't he on the seating subteam?"

"He and Mason want to do the frame. I like being on seating, I like problem solving and creating things, so this swivel seat is right up my alley."

"Well good luck with it!"

After Spring Break

"Good morning!" It's been more than a week since I've been in the engineering department, but spring break has come and gone and as I make my way to my office, I spot Alexis and Mateo in the hall. "How was your break?"

"It was good," Mateo smiles, "I got some homework done."

"Good," Alexis also responds, "I got some much-needed rest. How was your break?"

"Eh," I answer honestly, "I tried to get some rest and some extra work done and ended up not really getting either. Oh well. What's on the agenda for the bike project now that you're back?"

"We were getting ready to go to the bike lab and check if all our supplies are in, you can join us," Alexis invites.

"Cool, let me grab my safety glasses and I'll see you over there!"

The bike lab has been rearranged; the tables are now pushed together in three clusters providing more space between. The numbers on the side of each table that meant nothing before now correspond to a numbered locker and the team that's been assigned that space to keep their items. On the tables and in the lockers are items that have been purchased for teams based on the bill of materials. Some parts have been pulled from the bins of recycled parts and closet of wheels and frames and are also on the tables of the teams that have laid claim to those items.

At the middle cluster of tables, three students are standing facing a table of bicycle parts. These are Wednesday students. Apart from my role of ethnographer, I'm still in the role of graduate student. My schedule of classes has meant that I don't interact

with the Wednesday students much. I've become very familiar with the Tuesday morning crowd, that's the section that Teams Up & Down, Herding Cats, and Engaged all attend. However, the other sections have many students who I know little about. I've seen these students here and there, but I don't know their names or anything about their team.

Their demeanor suggests that this was not a social gathering. With eyes looking down at the parts in front of them, they each in turn pick up a part, somberly examine it, and place it down on the pile.

"How's it going?" I ask in a low voice mirroring their own somber appearance.

"It's going," the one in the middle replies but the other two just shake their heads.

"Is it not going, well?" I press further.

"We need a complete redesign of our bike," the one on the right states.

The one on the left tries to clarify, "we don't have to redesign everything, just the frame, so basically everything."

"Why?"

"The professor said the sides were too heavy."

"We just found out this morning, that's a great thing to come back to after break."

"That stinks." I feel bad for this small group of despondent sophomores and wish them the best as I leave them picking through parts.

The mood by table four is more upbeat. That's where Alexis and Mateo are gathered with Mason as the three of them compare the parts on the table to the list in Mason's hand. Leaning next to their table are the two large cardboard boxes containing the not yet assembled bicycles they purchased for parts.

"How's it going?"

"We're missing a couple of parts but should be able to start constructing the frame." As if on cue, the staff member responsible for ordering parts comes in to tell these members of Team Up & Down that two parts couldn't be ordered, and so they discuss what they can use instead. From the conversation, the necessary modifications appear to be minor.

On the far side of the room, some other sophomores have come in to look at the parts that have appeared in their absence. This room has gotten to be a much more interesting place to be now that it's full of parts and students.

* * *

Walking past the bike lab is part of my routine now, I do it several times throughout the day. The room is typically empty in the mornings but picks up activity in the afternoon. I know that some of the times the room is empty is because most of the sophomores are in class elsewhere in the building or on campus. I also know that the sophomores are in and out of the bike lab in the evenings when I'm not on campus. The students are a week into the build phase of project, and I'm delighted at the notes I've been able to take: notes about communication, notes about problem solving, notes about the lives of undergraduate engineering students in a project-based program, notes about problem-solving. There's a lot of problem solving.

I walk the halls of the engineering department, a laptop under one arm for taking notes, and safety glasses perched on my head. I've long since abandoned my notebook in favor of jotting notes into a word document and expanding them back in my office. I make my rounds, peering into the suite of professors' offices and glancing into the study rooms. I decide I should walk past the bike lab then go downstairs and check out the

fablab. As I turn the corner to walk to the bike lab, I see the client. We exchange pleasant greetings. I've talked to the client a couple of times. First, to tell them who I am and why I'm hanging around, then to ask them a few questions about what it's like to be the client on this project. Seeing them today provides another opportunity to check in.

"Good morning! How are you?"

"I'm great, I just met with a couple of students to check out their designs," the client tells me with a smile.

Darn, I think to myself knowing that if I had ordered my morning just a little differently, I could have captured notes about the student-client interactions.

"So, how's the project going?"

"I think overall it's going well, but I haven't talked to all of the teams about their final designs yet. I'm worried that the teams that haven't reached out to meet with me are building bikes I won't be able to use."

"Oh really? That would be shame."

"It would be, these students are working so hard. I'm going to feel terrible for any team whose bike I can't ride when it's time for the final presentation because I know how hard they're trying."

"Do you think it's likely that the teams you haven't spoken with recently are building bikes that won't work for you?"

"One team was really stuck on a recumbent style bike early in the semester, but I showed them how hard it is for me to get up from 8 inches off the ground and they understood they needed a different design. That's the kind of information every team

needs from me." The client shrugs, "The designs I have seen are really incredible though, what a talented group of people these sophomores are."

"I agree."

Bidding the client farewell, I continue rounds. The reason I make rounds like these is so I don't miss out on interesting interactions, like the interactions of the students with the client, but of course I still do. Just up the hall from the bike lab is a stairwell that will take me down to the fablab. The fablab is where the welder and power tools are, and like the bike lab it is typically empty in the mornings. It's still early in the day and as expected, there isn't much going on downstairs. One of the fablab frequent flyers is working away at a personal project inside. I wave at them through the glass but don't bother going in. Only the experts and student employees have swipe access to that space so it's harder to just pop in. I could tap on the glass at any time and someone would let me in, but it doesn't seem justified today.

Down the hall, a handful of the sophomores are gathered in the hall getting ready for the lab portion of their Statics and Dynamics class. In the machine shop, a couple of apprentices are busy at work. There are a couple of experts downstairs, overseeing the work that goes on down there, ready to help the students with problem solving when it comes up. Sometimes I stop and chat with the experts downstairs when there isn't anything else going on but today I just make my way back upstairs. I'll go to my office and work on my homework for a while. I'm usually the only person in that room, it's a good, quiet place to get stuff done. One of the engineering students informed me that I am known now as "that lady in the corner lab."

* * *

Afternoons in the bike lab are more interesting. Next to a few of the tables in the room, human-powered vehicles are taking shape. Next to other tables are piles of parts that have been mostly untouched at this point. When I get to the bike lab, I see most of Team Up & Down has gathered to work. I've noticed that some of teams favor working all together as one large team while other teams will have just a few people doing most of the fabrication. Team Engaged seems to always have somebody in the lab working, but it tends to be the same couple people from the team instead of everyone altogether. I haven't seen anyone from Team Herding Cats in the bike lab for a while. It's possible that they are gathering there in the evenings when I'm not on campus, but the pile of parts under their table suggests that probably isn't the case.

As a researcher, it's always nice when I find work happening that I can observe. Team Up & Down's schedule corresponds well to my own which feels like a lucky break. For everything I get to observe, I am always left knowing, worrying, that I am missing a lot of what is going on. As I move through the bike lab, towards team Up & Down, I see parts of bikes that have been assembled since the last time I was in and I know that with each part that comes together there are interactions between group members, professors, experts, and the client that I've missed. At the middle cluster of tables, there is half a frame that has been pulled from the back. Taped to the front of the frame is a torn-out piece of notebook paper with the words "Don't Touch" scrawled across it.

Hailey is standing nearby and doesn't seem busy, so I ask her, "what's up with the sign?"

"Oh!" Hailey replies with a spirited grin, "so…"

I get excited knowing some bike lab gossip is coming my way. Who doesn't love a little drama?

Hailey continues, "another team found this frame, no, wait, THIS team pulled this frame from the back and had it on their table, then a DIFFERENT team took it and put a sign on it saying it was theirs. Then this team tore off the sign and took it back and put THIS sign on it.

I gasp, "drama!" and Hailey and I laugh.

I cannot be in the spaces often enough to catch everything, or even most things. However, the students don't mind sharing with me what I've missed. Of course, these events are described from their perspectives, but there's nothing wrong with that. I like hearing how they are making sense of the project and all things related.

Changing the subject, I ask Hailey, "so what are you working on today?"

"I think the frame? I have to go now though, but I'll help out later," Hailey tells me before tucking her safety glasses back in her bag and leaving.

Alexis and Mateo are hovering over Mateo's laptop. Jacob is using a screwdriver to disassemble a chair. Next to him, Sara is leaning over, eye level with the table, scrutinizing the movement of the device she's working on. Cody and Mason are holding pieces of bicycle frame, some of which has come from one of the bikes they purchased and at least one part is from the closet of recycled bicycle frames. I don't see Doyle around today, but I only occasionally see him anyway. Hailey and Doyle haven't stepped forward to take the lead on any particular part of the build like Cody has for the frame, or Sara has for the seat. Jacob and Mateo aren't leading any part of the build either, but they are reliably there when it's time to fabricate.

"Whatcha working on?" I ask no one in particular.

Cody responds to my query, "I'm getting ready to weld this bad-boy together."

"Oh, exciting."

"Did you not need the parts from this bicycle?" I ask noticing that the only one of the boxes has been opened.

Mason answers, "I don't think we will. I found this in the back and it's almost exactly what we had designed on our bike. We're just going to use this." Mason is pointing to a previously welded part of a bicycle frame. It looks like it must have been part of one of the human-powered vehicles from a previous year because it has the distinctive mismatch of paint colors and materials that comes from pulling parts from different sources and welding them together.

"Well that's convenient."

"There are a couple of adjustments we have to make," Mason admits, "it's not a perfect match, but it should save Cody some trouble on the welding."

Cody has got pieces of frame to be welded, on the sides of the tubes I can see that painter's tape and marker have been used to mark the pieces. "Front fork, connect here." Cody looks like he is ready to go and makes his move towards the door.

"Stop, Cody," Alexis instructs, "you're not ready."

"What's not ready?"

"We're still figuring out where the support bar needs to go."

"Well I could still start with these," Cody objects but stays put anyway. Alexis abandons the laptop and joins Cody and frame pieces. Mason, Alexis, and Cody together

start holding up pieces of frame and positioning them how they will be on the finished product.

Mason takes the lead on determining how the pieces should come together. “As long as it doesn’t hit back here, and is high enough off the ground here, it’ll work.” Mason tells the other two. Rather imprecisely, Cody marks the tube under consideration with a screw noting the correct position identified by Mason.

I circle around the table to see what Mateo is working on. On the laptop is the team’s CAD model. Mateo tells me, “there have been some changes made so I’m trying to update it so we’re all on the same page and can keep moving forward.”

“That’s smart,” I tell Mateo. It certainly seems like a good idea.

“But,” Mateo admits, “I don’t have all the changes so it’s not exact. It should still give everyone an idea though.”

“Hey Mateo,” Cody interrupts us, “you wanna come with us? We’ve got to cut more tube before I can start welding.”

“Sure,” Mateo replies and gets up to join Cody and Mason in the fablab downstairs.

“Can I come too?” I ask the trio.

“Sure,” Cody smiles as the three of them walk out the door. Before following I decide to check in with Jacob and Sara.

“How’s it going?”

“Eh,” Sara replies, but doesn’t take her eyes off the part she’s working on. I guess the swivel seat is still giving her grief.

I turn instead to ask Jacob what they are up to.

"I had my mom send me this chair, it's mine from my room, we're going to use to it for the seat," Jacob tells me. I smile to myself knowing what it might have been like being the mom on the other end of that phone conversation. "Hey mom, could you ship my chair to me? No, I don't want to sit in it, I want to use it for parts." I'm glad Sara has Jacob helping her with seating today since the other members of that subteam are sparse. Jacob uses the hand tools a bit awkwardly, it seems like he isn't quite sure where to start, but he presses forward nonetheless.

While I'm watching Jacob fumble with the screwdriver, I notice one of the Wednesday student's has moved into the closet in my line of sight. From a plastic bag they pull a Styrofoam leftover's container. That's when they see me seeing them. I don't care that this student is eating in the bike lab. If I saw someone doing something dangerous I would say something, but it doesn't bother me that this student is taking a break from whatever they were doing to eat something. They look back at me nervously, I try to make a gesture of looking away, but they aren't going to take the chance. They walk past me, grab a stool, and take it out into the hall to eat some food. I decide this is probably a good time to check on the trio in the fablab downstairs.

Team Up & Down isn't the only team with members working in the fablab today. I see the usual suspects from Team Engaged and a handful of students from some of the Wednesday section teams. Cody, Mason, and Mateo are at a device that holds tubing so it can be cut at the appropriate angles to be welded together. Watching them for a few moments, I see that Cody likes stepping into the role of instructor on these tasks. He tells the other two what to do and then steps back to observe. He likes working with his hands, that's clear, but he also likes working with others, especially if it seems like there is

something he can teach them. He isn't one of the experts in this space, not officially at least, but he does seem to enjoy stepping into that role. Sometimes I wonder if he actually knows what he's talking about.

As I watch the trio from Team Up & Down preparing tubes for welding by cutting them, it registers that there has been an unusual amount of activity at the bench vice behind me. I turn around to see that some of the Wednesday students are trying to get something unstuck and I go observe them for a while. Apparently one of the Wednesday students was using a tool and got it stuck in another tool. They've been joined by Michael, the student I met during the bike breakdown; he ended up on Team Engaged. He has suggestions that he shares with confidence, but the pieces are still stuck together. He tries himself, but still nothing. After several minutes of this, a student employee in the fablab, one of the engineering upperclassmen, comes over to help. Still, even with the three of them, and a few more onlookers offering advice, that piece is not budging.

Cody is still cutting some angles into the tubes. Mateo has a hand file and is going over parts of the tubes that need to be welded. Mason was helping with the tubes too but since there doesn't seem to be more for him to do at this point, he wanders over to the bench vice to try his hand at breaking apart whatever it is that is stuck together. Some of the people at the bench vice lose interest and move on to the tasks that brought them into this space in the first place. Others leave and come back if they thought of something else to try. Just when it seems like the pieces will be stuck together forever, the expert comes in. The expert listens to the Wednesday student explain what happened while the expert assesses the pieces. When the Wednesday student stops speaking, and as they watch on anxiously, the expert grips one part with pliers, turn, and POP, the two tools are apart. It

took less than 30 seconds, including the explanation beforehand. I guess that's why they're the expert. The Wednesday student stands there slack-jawed, the expert shrugs and walks away. I laugh.

Cody comes over to tell me he's going to start welding. Not all of the teams have somebody on their team who can weld, but welding training is one of the many options available to students and Cody did his training the previous summer. "You can come watch if you grab some gear," he tells me. He's pointing to the cabinet with extra gloves, jackets, and helmets—all required and necessary if you want to be behind the divider when welding is going on. I thank him but it's getting late in the day and I have to pick my child up from daycare.

Two Weeks until Alphas are Due

"Your Alpha prototypes will be evaluated for functionality, usability, performance, and reliability." There's about fifteen minutes left in class and the professor is reminding the students what they'll be looking at when they grade the Alpha prototypes. Grading in this class is confusing to me and the students don't seem to know much better than I how their final grade is going to be calculated. I wouldn't be a fan of that personally, in undergrad I kept excel sheets to weigh grades so I would know exactly what I needed to get on my final exams to get an "A." In this class they have exams, individual assignments, team assignments, and the project. Some things are pass/fail. For example, the students either pass the safety check that comes before the Beta prototype or that's it, zero. But is that a zero in the class, or a zero on the project? I'm not sure. Other assignments are awarded points.

Wrapping up the discussion on how the Alpha will be graded, the professor passes back the students' midterms. They don't get to keep them, "You can look at them and then turn them back in to me," the professor explains.

I'm sitting at the back table with Alexis, Mateo, Mason, and Doyle. One by one they are handed their exams face down and begin flipping through. No one seems particularly excited by what they see.

"How'd you do?" I ask Alexis.

"I did okay," she responded dryly. I didn't press further.

After all of the exams had been passed out the professor writes the class average on the board and tells the class that they are going to quickly go over the exam together. "66, 51, 81." That's what the professor has written on the board. The class average, the lowest grade, the highest grade. My goodness, now I understand the somberness of mood around me. The students flip through their exams as the professor explains what they would have gotten full credit for, partial credit for, and no credit for. After the explanation of how things were graded the students are given five minutes to take notes, spot anything the think they think was graded wrong. They cannot take pictures of the exam, but they can meet with their professor and see the exam any time. During these five minutes, the students begin to converse about the exam.

"This is freaking stupid," Doyle shakes his head.

"What did you put for number 6?" Alexis asks Mason.

"I got that one wrong. Why? What did you put?"

"Mine is marked half credit, but I think this was what the professor said was the right answer," Alexis turns open the exam and shows Mason.

"Yeah, that wasn't what I put at all," Mason sighs. He sounds frustrated, and maybe a little defeated. He adds to Alexis, "Your answer looks right to me though, you should ask the professor."

Doyle huffs again in frustration, "most of this stuff doesn't even have anything to do with the project."

"How'd you do?" I ask Mateo who is still looking over his answers.

"I did okay, I got 81. "

"Mateo, that's the highest score, that's awesome," I say quietly just to him so as not to further upset Doyle or Mason who both seem pretty put out at their grade. Mateo smiles and shrugs in response.

It's time to hand the exams back to the professor. Class is over. Several students are sticking around to talk to the professor about questions they thought they should have gotten credit for, including Alexis.

Mason turns to me and asks, "Are you still looking for students to meet with you and talk about the project?" He's referring to an email I sent to him and a couple dozen other students earlier in the semester. The email invited them to pick a time to come meet with me in my office so I could ask about the project. There were three people who responded, and they do drop in from time to time, but overall I had abandoned that model early on because getting students to find time in their schedule was a lot harder than just running into them in the halls and labs and chatting with them. My "informants" ended up being the people who were most frequently in the bike lab and not necessarily the few students who were willing to go out of their way to chat with me. Still, I was so excited that Mason wanted to chat, he usually seems too busy for conversations with me. I was

worried that my presence annoyed him! I'd really like to ask him more about his MAGA sticker and how he is navigating a campus that I've heard other conservative students describe as very liberal. "Sure!" I tell him perhaps a little to enthusiastically.

"Can we get extra credit if we do?"

"Um, no, there's no extra credit available for talking to me."

"Oh. I bet you would get more people to talk to you if you offered extra credit," Mason says as he picks up his stuff and leaves. I pick up my wounded ego and leave as well.

10 Days until Alphas are Due

I make my way through the halls of the engineering department to see what is going on and where. Beep, clang. Beep, clang. That's the sound of doors opening in the engineering department. The beep indicates that you have swipe access to the room you are trying to enter. A longer, higher-pitched beeeep means that you don't have access. The long beep is not followed by clang, the clang is the sound of the metal door opening. The beep-clang of doors opening becomes part of the sounds of the overall environment, like the sound of birds in the forest or cars on a busy street—you expect it, you don't often pay attention to it but if it were suddenly gone, you would notice. As I get close to the bike lab I realize my card to swipe into the room isn't in my pocket. A senior student I've chatted with a few times passes me in the hallway as I approach the door, we exchange a friendly greeting and when he notices that I have no card in hand he instinctively reaches for his and swipes me in while we trade "have a nice day." Beep, clang.

The bike lab is busier than usual for a morning. That's because this is one of the mornings that the client can be on campus to answer questions and check out how the bikes are coming together. Students from several teams are hanging out in the bike lab, waiting their turn to talk to the client and get feedback. Right now, the client is talking to two members of Team Engaged. Looking at their human-powered vehicle, it looks mostly put together, but one of the team members has told me that they are still working out issues with propulsion and they haven't added brakes yet.

"How do I get on it?" the client asks the students from Team Engaged.

"You just get on," one of them answers. The client stands there and gives them a few moments to realize that they are going to need to offer more guidance than that.

Trying again, the student says, "You, um, you can hold the bike here on the frame for stability and then bring your foot over this bar. The client attempts the motions as directed by the student. The frame works well for providing stability but only because the other student is holding the bike in place so that it cannot move while the client tries to mount the bike.

Acknowledging this, the student holding the bike tells the client, "We'll add a parking brake so the bike stays put when you're getting on." That doesn't seem to be the only issue though. With their hand in place, and body positioned to mount the bike, the client is unable to swing their foot over the center bar to mount the bike. The client repositions and tries again. When the client turns one way, the front fork blocks them from getting their foot over. When the client turns another way, the bar the seat is attached to becomes an obstacle. The two students do their best to steady the bike and

offer suggestions. Now I see why the client started with such a simple, but essential, question. If the client can't get on the bike, they can't ride it.

"Grab that block for me," the client tells one of the students. The student goes to retrieve the block from the other side of the room.

I take a moment to look around. One student from the Wednesday section is hanging back, seemingly waiting for the client to be available. At table four, Jacob and Cody are tinkering with some gears. I suspect they are waiting for a chance to meet with the client too since this isn't a time of day that they would normally be in the bike lab. A member from Team Herding Cats stops in, but it looks like they are dropping off a part and don't plan to stay.

"How are you doing?" the client addresses the team member from Herding Cats jovially.

"I'm good," the student smiles, but they look past the client and not actually at them. The student continues to smile and nods their head as they head back out the door.

Huh, that looked polite, but it felt like the student was avoiding talking to the client. I can't tell if the apparent avoidance is because the student is uncomfortable with the client or because they know they don't have much to show for their project. I glance at the table where team Herding Cats "bike" is. Most of the teams have something that looks like a bike now, which is good, the Alphas are due in a little more than a week. But this team, oye, this team has a pile of parts. "What are you doing Team Herding Cats?!" I add to my notes. "Where are you?? Where is your bike??" At first I thought Team Herding Cats might be working in the lab when I'm not in the building, but increasingly I

notice that the people I see regularly appear to be further along in their work then the people I don't see. It's hard to tell though.

I've already noticed that I cannot tell which systems are going to be "easy" to put together and which are going to frustrate the students for days or weeks at a time. It varies team to team too. One team may have very complex braking and steering but simple propulsion while another team will have complex propulsion and simple components on the rest of the bike. And sometimes the "simple" parts don't come together as expected. It's impossible to tell exactly how much work each team has left to do just by looking at what parts are already on the bike. Except, it's pretty clear that Team Herding Cats is behind.

The student from Team Engaged places the block next to the bike and the client is able to step on it and then up and over the bar to mount the bike. The students and the client talk about adding a step or lowering the bar that was difficult to get over. Then the client tries steering. It looks like the steering system will work fine for the client. The students thank the client for their time. The client thanks the students for their hard work. Those two students turn to the table and are pulling the parts they need to keep working.

The client looks around the room to see who's next. The student from the Wednesday section approaches the client first and together they make their way to the human-powered vehicle this student's team has been working on. I recognize the bike right away. Unlike many of the other teams who are making a custom frame, this team has purchased an adult-sized tricycle to modify for the client. As such, this team has had a complete-looking project sitting in the bike lab since the first week of the build phase

when they unboxed the trike and put it together. They're modifying the prefab product by adding a motor to assist and nice details, like sideview mirrors.

The client has trouble getting on the tricycle, it isn't built to accommodate the client's body or limitations of movement. Of course, the other vehicle that was tested today was built specifically for the client and there were still issues getting on and off. The student and the client work together to get the client on the bike. With the client on the bike, the student lifts the front tire just off the ground so the client can try pedaling without going anywhere.

"My leg just isn't going to stretch that far," the client tells the student. The client is on the seat, trying to pedal, but the pedal extends further down then the client's foot will go. The client continues, "I think you're going to need to lower the seat and shorten the crank arms on the pedals."

I watch with curiosity. The advantage that this team has over the others is that they bought a full tricycle to start with. If this student follows the client's recommendation, they will have to cut and reweld the frame. That is why I am not surprised to hear the student reply, "Hmm, we could do that, OR, we could make the pedals bigger. If we added blocks to the pedals that would do the same thing essentially."

The client thinks about this for a moment, "I suppose that could work." The student tells the client they are going to take this information back to the team and meet with them again next week with some solutions. The client moves over to where Jacob and Cody have been waiting, and perhaps doing something productive with some gears, I can't tell. Instead of tuning in to that conversation, I decide to follow the Wednesday student out into the hall.

"How's your project going?"

"Pretty good, we've made a lot of progress. Still trying to figure some things out though."

"Yeah, I saw that you're still working some stuff out. I get the impression that you don't want to have to cut your frame."

"No, but I don't think we'll have to, the client said modifying the pedals would work just as well."

I think to myself, "Is that what the client said?" I don't question the student's interpretation of events out loud though, instead I ask, "Have you met with the client frequently?"

"Someone from our team has met with the client every week that they've been available. I think we're the only team that has done that."

"I think so too," I answer honestly.

"I was really moved by the client's story, like it made me tear up when they came and spoke to us in class. They're a really cool person and I've really liked getting to know them. Everybody on our team wants to do right by the client." I can't say that I agree with this student's interpretation of what the client was communicating, but I genuinely believe this student cares about the work they are doing, and it makes my heart glad. I've met so many wonderful students and I feel invested in the outcomes of this project. I want to see them succeed.

"That's really cool, good luck with the rest of your project," I tell the student as they continue on their way.

Back in the bike lab, Jacob and Cody are speaking to the client. The client can't get on their bike, because there is no seat on it, but it looks like the two students are updating the client on the progress on their dual propulsion system. The client likes what they've been working on so far and seems excited about having the option to pedal with feet or use the upper propulsion system with their arms. Jacob has questions for the client about the handlebars. Cody might just be here because he can be or because he wants to hear what the client has to say about the frame, which came together nicely. Jacob is holding the braking mechanism up to the rotating cranks that make up the steering/upper propulsion system. There's a lot going on with the front of the bike with steering, braking, and propulsion all happening in the same spot and the parts must be positioned so the client can operate all three.

"I think it's going to be hard to maneuver that way," the client informs Jacob.

"What if we position it here?"

"That's a little better, can you turn it?"

"Like this?"

"Yeah, I think that would work. I could do that."

"Okay. Okay, good," Jacob reaches for something on the table to mark the position of the brakes.

I know Team Up & Down has more things to figure out before their Alpha is ready but apparently that was all they were ready to ask the client about today. I wait until the client leaves before asking Cody and Jacob about the project, "how's it going?"

"Check out this fancy welding," Cody tells me, pointing to bike frame.

"Hey, that's nice!" I tell Cody.

"Yup, it's tack welded here, and here, in case we have to move this support, but the rest is permanent," Cody beams.

"Great job, Cody! Did the expert help you?"

"The expert gave me some pointers, but I did the welding myself."

"Well done. Well done." I love these show-and-tell moments. "So, do you think you'll have to move the support?"

"We're adding a chest rest, but I don't know where it has to attach. If we attach it here, the support could get in the way. We could attach it to the support, but then it might get in the client's way when they are getting on and off the bike."

Many of the bikes do have chest rests so I'm not surprised Team Up & Down has decided to add one too. "When did you decide to add a chest rest?" I ask Cody.

Jacob breaks into the conversation, "the client said last week that they like the designs with the chest rests."

"Hm," I wonder aloud, "if the chest rest wasn't in the original design do you think it might throw things off to add it now?"

"No," Jacob replies, "It'll be fine, and it's what the client wants."

In agreement Cody shrugs, "It won't be hard to add it on."

Someone from the next table walks up while we are talking, "Cody you know metal, is this aluminum or steel?"

"I have no idea," Cody replies, but he takes the handlebar from the student, files the end a bit, and answers the question anyway, "it's aluminum."

The other student's countenance falls at this revelation. From hanging around I know this is because you cannot weld aluminum to steel. This student will have to find another piece to work with if they want to add it to the other parts of their frame.

The student from Team Herding Cats who had been in just a bit ago returns. They've gone over to the two members of Team Engaged who are still working on the other side of the room. I take my leave of the Team Up & Down members to see what is happening in that corner.

"Did the client have trouble getting on your bike?" the student from Herding Cats asks.

"Yeah, there was some difficulty."

"Could the client step over the bar?" the student continues asking pointing to the bottom bar of the bike that extends from front to back.

"No, it was too high. We're either going to lower it or add a step."

"How high can the client step?"

I am incredulous listening to this student. I think to myself, "the client was just here! You saw them, you could have asked them all of these questions!

Seven days until Alpha

The bike expert usually comes in the evenings, which means I don't usually get to see them. However, as the deadline for Alphas approaches, this expert has made themselves more frequently available. It's a late afternoon in the bike lab and students from at least four different teams are in the bike lab working and/or waiting for a chance to talk to the bike expert. When I get in, the expert is talking to Mason.

"It's not a bad idea at all," the expert tells Mason, "it's just complicated, let me

tell you some other options to consider." When a student tells me they made a change on their bike, I follow up by asking where the idea to make the change came from. Often, the answer is, "the expert suggested we do it this way." Sometimes though, the answer is, "I called my dad and he suggested we do it this way" or "I watched a YouTube video to figure out how to it." From what the students have told me, it seems the expert doesn't tell the students what to do, they lay out the choices and then tell the student which of those choices are feasible with the time and resources the student has.

I make my way around the bike lab to see what other teams are up to. Michael from Team Engaged is leaning over their bike with some hand tools so I ask what he is up to.

"Well I finally worked out the problem with propulsion so now I have to fix it."

"Oh really, what was the problem?"

Pointing to the parts as he explains, he tells me, "the short chain needs to be absolutely straight, but the longer chain can be at an angle, I had the short chain at an angle and it kept popping off."

"How did you figure out the solution?"

"I went to the bike shop in downtown Townieburg. There's fellow there who works on trikes. I brought in the sketches of our design and explained the problem. He was real helpful."

"Wow, how resourceful! So he told you what you needed to do?"

"Well, he told me what my options were and the "right" option wasn't in the budget. I don't want to say what we're doing is the incorrect option, it's just not the traditional solution."

"Well it's looking great." I turn to the student who stepped up to observe while this member from Team Engaged and I spoke. "Are you on this team too?"

"Oh-ho-ho," the student laughs a bit sardonically, "I wish! I'm on THIS team." With a sweeping arm motion the student gestures to the place where Team Herding Cats would be working, if Team Herding Cats was working.

"Oh, sorry," I don't clarify if I'm sorry for getting the students mixed up or because this student is on Team Herding Cats. "Where's your bike?"

"Well," the student says picking up two wooden blocks, "this is our propulsion system." He looks at me with a glare suggesting a full understanding of the predicament he is in. I cannot imagine this team is going to pull this together, there doesn't seem like there is any way. The other student I was just talking to has been in this lab several times a week from the beginning of the build phase and they are still pulling together their project. With a lowered voice I lean in and ask, "What is happening on your team?"

"There are only four of us who are doing any work. Our project manager hasn't done anything so a few of us have stepped up, but even when we assign the project manager a task, nothing. At least we have Olivia, she's going to try welding the frame today, then Sam and I are going to do something with this propulsion system."

With a pained expression, I wish the student, "good luck."

"Thanks…"

At the next table over the expert is talking to two engineering students who are listening intently. One of them tries to demonstrate they understood the expert's explanation saying, "so everything needs to be tight as possible?"

"No," the expert states, "everything needs to be correctly torqued."

My heart goes out to these students. Everyone is trying to become an immediate expert in bike-building to complete this project, they are looking for rules to govern their choices but instead have to navigate a lot of specific information. The struggle continues as the expert walks them through more necessary improvements.

"We're trying to remove this cassette," one student tells the expert.

"That's a free wheel."

"Do we use this tool?"

"No, you need the free wheel remover."

What is a free wheel remover, anyway? People are busy around the room. As usual, for each group of students working, a couple have their hands busy, a couple might be leaning over a laptop or the others guiding decisions or documenting the work, and a couple will be there without something to do. The student without something to do on Team Up & Down is Jacob. He is sitting on a stool watching the other members of his team. Mateo and Mason have their hands busy, while Alexis and Cody are standing close by talking through taking some of the parts off. Alexis is talking to Mason and Mateo directly, sometimes offering suggestions, sometimes asking questions. Cody all the while leans back on his elbows on the table and throws in a few, "don'tcha gotta take that other part off first?" It looks like the seating subteam isn't here for this work. There is still no seat attached to the frame.

"How's it going?" I ask Jacob.

"Fine," Jacob replies, but I see he is feeling kind of sour today. That isn't unusual for Jacob. I wondered at the beginning of the semester if he was going to be a problem on his team but it doesn't seem so, sour or not, Jacob shows up and accomplishes his given

tasks. Knowing that Mason was speaking to the bike expert I ask Jacob if there have been any major changes to the design.

"Nothing major," then pointing to a sketch on the table, "but we need to move the cross bar for support. We've got to remove, the uh, parts there, to do the welding."

It seems Jacob struggles when it comes to the specifics of the propulsion system, even though he is on the propulsion subteam. The others appear to have enough of a grasp of what needs to happen though. Alexis is on the floor now inspecting the parts that have to come off.

"Hold on," Alexis says, "let me get a crescent wrench." Standing up, Alexis approaches the small group of students working at the next table. "Can I borrow a crescent wrench?" Alexis asks.

"Don't you have a crescent wrench?"

"We do have a crescent wrench, but we need a second one."

"Fine," the student says and digs into their toolbox for their crescent wrench. This student then turns to the others at their table and instructs, "I've got to go, make sure you clean this stuff up," the students adds as they pick up their bag and glances back at Team Up & Down, "or guard it."

The bike expert is gathering their things to go, and I see that they have the front of a bike under their arm. Seeing me watching, the bike expert says, "this fork is going on a field trip." They chuckle, and leaning in with a tone of voice that sounds like a wink add, "I have a fork widener at my shop that team is going to need if they are going to fit a motor between a wheel and this fork."

Five days until Alpha

Several members from Team Engaged are in the bike lab and one person from one of the Wednesday teams. "Where's your team today?" I ask the Wednesday student.

"Good question," they reply.

I see Alexis and Mateo coming down the hall and watch to see if they are going to turn into the bike lab. They do, oh joy.

"Hi, what are you working on today?"

Alexis replies, "Hi, we're going work on a 'conversion kit' for the steering slash propulsion system. What are you working on today?"

"I am going to hang out in here for a while and then get to work on a twenty-page paper I have due."

"I wouldn't want any part of that," Alexis replies, "give me Statics and Dynamics any day but keep your twenty-page papers to yourself."

We laugh. When the topic of challenging coursework comes up, I tend to pull long essays out of my back pocket. A few times, students have implied that they work harder than other disciplines on campus, but their writing tends to show up in reports and memos. It's the one thing I can point to and say, "look, I do hard stuff too."

When Alexis gets to their team locker she stops short, "why is this unlocked?" She looks at the only other team member with her at the moment but Mateo shrugs. "I hope nobody stole anything; you can't trust anybody," Alexis states, clearly unhappy that the locker wasn't properly secured by one of her teammates.

It certainly doesn't look like anything is missing and I would be surprised to find out if the dubious behavior sometimes alluded to ever actually took place. Except for the

contested ownership of an old piece of frame, I haven't observed any nefarious behavior among the students.

Alexis takes out a plastic bag of parts from the locker. "I wish they would have told us that we wouldn't be able to use the rest of our budget," Alexis tells me.

"You didn't get to use your full budget?"

"We could spend up to $400 before spring break, but we forfeited anything left over."

"OH…"

"We didn't know that. We saved as much money as we could thinking we could buy more parts later."

"So what do you do if you need a part now?"

"We have to pay for it ourselves," Alexis says nodding to the plastic bag that probably came from Lowes or Home Depot.

"Is that your conversion kit?"

"Some of it. We're going to dig around in the back for other parts to use."

"Is it just you and Mateo working today?"

"No, the others are coming in too, they're just not here yet."

Across the room, one of the bike lab regulars from Team Engaged, Michael, is calling out to a teammate trying to leave the room with large, round gear in their hand. "Get a hammer and bang it GENTLEY, but you really got to hit it, but don't damage it, but just tapping it isn't going to do it"

"I've got it," the student with the gear presses back and heads for the stairwell to the fablab.

Michael turns to another person on the team and 'suggests' they offer some assistance, "go down and help him, will ya."

I tell Alexis, "I swing back by when the others get here and see how it's going," and head downstairs too.

The two students who were sent downstairs for this task of gently banging on the gear are trying to make the bent disk straight. One of them asked a professor on the way down for some guidance and at the professor's suggestion they have the gear in a vice and are pulling at it with pliers. They tighten the vice, pull, loosen the vice, rotate as necessary, and pull some more. Then they take the gear from the vice and lay it on the table. Still bent. They have a different idea and put the gear into a vice that holds the part horizontally instead of vertically. They try pushing down on it to bend it but when they examine it, it is still bent.

"I say we try pulling up now."

"I think we need to push down."

"Let's push up. One of us could lay on the floor and push up on it with our feet."

I've been typing some notes on my laptop but look up at this suggestion. I expect to see the student smiling, but their furrowed brow suggests they are not joking. Neither of them lays down though. Instead, one of them grabs a wooden block and some "C" clamps. They lay the gear on the worktable, place the block on top, and use the "C" clamps to fasten the block down onto the gear. One student goes to the tool cabinet and comes back with a hammer. I've lived in homes heated with wood and suspect I know what is about to happen to that wooden block.

Whack!

Pop.

Now the students have a bent gear and two smaller wooden blocks. They look around the lab nervously, but I don't think anyone is going to be too concerned about that wooden block. One of them eyes the gear on the table.

"I think it's a little straighter now."

"Yeah, it looks straightish."

They put away the tools they used, and the split block, and go back up to the bike lab. I'm going to go too but first I want to capture the various attempts at gear straightening in my notes. Before I finish typing, my attention is drawn to a tap at the fablab door. It's Michael, the student who had been giving instructions to the other two. Well, I guess he took one look at that gear and decided it wasn't good enough. I hop around the table to let him in the room. Only experts and student employees have swipe access to the lab but whoever is nearest the door can let in a person waiting to enter. I don't know if that is policy or merely practice, but I picked it up from the others who use the space. I open the door with a smile. He nods back and move past me to the table where his teammates were working at the gear just moments ago. I see him get a hammer from the tool cabinet and discern that the lab is about to become even louder than usual and so I exit the door I was still holding open and go back to the bike lab.

The first students I pass when I enter the room are the two from Team Engaged.

"Not straight enough?"

"I guess not," one of them replies.

The other adds, "Michael is smart but he can be stubborn."

"Is he the project manager?"

"No," the student says laughing, "he's just bossy. Actually, he's pretty much in charge of fabrication because he has the most hands-on experience in design and manufacturing." He points to tall student with sandy blonde waves pulled back with a scrunci seated at the far end of the worktable, "if you want to talk to our project manager, she's over there."

I move myself in the direction of his nod, to introduce myself to Team Engaged's project manager. She has a laptop open in front of her and is typing away with purpose. Seeing me walk up smiles and peers at me over the top of her screen.

"I don't want to interrupt you, you seem busy."

"I'm just writing up a memo for our team."

"Do you do a lot of memo writing for your team?"

"I do most of the memo writing, it works well that way."

"Well I'll let you get back to it then," I smile and turn to see who else is in the lab.

At the middle cluster of tables an annoyed looking sophomore is picking up parts that are cluttering the table. "Why do we have so many wheels? Are these our wheels? I'm 100% sure we don't need any of these wheels." Most of the tables in the room have a pile of parts on them. Lots of parts get pulled because they might be needed, only to find a permanent home on the table. There is also bits of cable, washers, nuts, and bolts scattered about on the floor among parts and almost completed bikes.

A few more members of Team Up & Down have come in and it looks like they are working together to take apart some handlebars. I watch for a bit noting that, unlike Team Engaged where members have very different roles based on particular skills, the members of Team Up & Down tend to work together placing less emphasis on subteams

and role designations. They have roles, to be sure, at this point I think only Mateo has any idea what is happening on the CAD model they have to turn in with their project, but there is more movement into and out of those roles.

While I'm watching them work Cody cracks a joke about Team Herding Cats. I wonder what roles Team Herding Cats has? Cody glances at me after the snide remark.

"Are you putting that in your notes?" he asks jokingly.

"Don't worry, I use pseudonyms. Remember?" Then I add out loud while typing, "Shmody doesn't like the other team's design."

Cody continues the joke, "Shmody is always talking shit about other teams."

We all laugh. Good times.

Team Up & Down has done as much to convert the handlebars to an upper propulsion system as they can today. They are going to need another part. Mason volunteers to pick it up and they agree they'll split the cost later. It seems like a good time for me to head back to the research lab.

Four days until alpha

I've stopped in the bike lab before going across campus to one of my own classes, but I cannot stay long.

Michael is working on the braking system for Team Engaged's bike.

"I hear you have some experience in fabrication and design?"

"I've helped out in a shop back in my home state the last two summers."

"How do you think that has influenced your work here?"

"I think it's helped. Things don't always come out in Solidworks, working in a shop helps you be a better designer."

At the next table over two Wednesday students, both men, are digging into one of the bins of spare parts.

"Do you think this will work?"

"Lemme see?"

"We could cut it here and make it fit."

"That's a good idea, bro."

It's nice to hear this student encouraging the other. I've noticed that as the deadline draws closer tensions have been increasing in this space, and the niceties decreasing.

Three days until Alpha

"Do you know the expert in the machine shop?" one of the upperclassmen asks a student from Team Herding Cats.

They nod in response.

"Yeah? Well, are you on his good side?"

The student pauses, then gives an unsure nod.

The Alpha prototypes are due in a manner of days and both the bike lab and the fablab are busy. In the bike lab, most of Team Herding Cats is pulling together parts of their bike. I note that it's the first time I've seen a couple of them working. The member who reached out to the upperclassmen is apparently trying to figure out how he can obtain two tie rods for their bike between now and when they have to give their completed alpha prototype in class.

At the worktable next to them, a Wednesday student with a thick Southern drawl is dropping expletives almost as often as small pieces of bicycle chain. He has a hand tool

that can take pieces of chain apart and link them back together so you can make a chain the exact length it needs to be. From the sight of it, this is not a particularly easy process.

"What are you doing?"

The student standing nearby begins to answer, "We're fixing this chai..."

They're interrupted by the student with the hand tool, "We're not doing shit, I'm fixin' this damn chain."

"Well," the other student lets out an uneasy laugh, "I'll go see what's going on in the bike lab then."

Oh goodness, I stifle a chuckle, it seems some students have less tolerance than others for team members who cannot find something to keep themselves busy. I decide to go upstairs too.

In the bike lab, the first students I see in the bike lab are three from Team Engaged. The project manager for their team is working on her laptop at the table next to their bike.

"Whatcha working on?" I ask her.

"I'm designing the presentation for our Alpha," she replies.

"Neat, how's the bike coming along?"

"Oh, it's done, we finished it up yesterday."

"Wow, you must be so relieved to be finished!"

The three nod and smile at each other and back at me, "Yeah, it's pretty great."

Micheal adds, "there are things we need to modify for the Beta, of course, and I'm sure there will be things to work on for the safety inspection, but this is ready to go for the Alpha presentation."

This isn't the first time I've heard students discussing what needs to be done for the Alpha versus what can be put off for the Beta. Unlike some of the other teams who are pushing off improvements out of necessity, because they are running out of time, this team seems to have decided based on other factors that certain tasks should be put off.

"What are you going to add for the beta?" I ask.

"A parking brake, and probably a basket. The parking brake for extra stability when the client gets on and off, the basket to make carrying things convenient."

At the next cluster of tables, some Wednesday students are trying to get the brakes working on their bike. I see one person make some adjustments, then another person watching the brakes for movement when the part on the handlebars is squeezed.

"Nothing."

"What about now?"

"Still nothing."

The student making adjustments lets out a dispirited groan.

"How long have you been working on these brakes?" I ask.

"Since yesterday," one states with a pained expression."

At table four several members of Team Up and Down are looking over the newly added seat. I'm so relieved that Sara's finally gotten the swivel seat sorted out. I know it's been one thing after another with that seat.

"It's a piece of shit." This is all that Mason, who is usually polite, can come up with in response to the seat on their bike. Circling around the bike, he is turning the seat, pressing on it in different directions, while Alexis and Cody look on from a couple feet away. Sara isn't here, I'm not sure when her subteam finished the seat and attached it.

Looking at the movement of the seat, I understand what Mason is getting at. It is meant to turn, from forward facing to the side, as Cody is quick to point out in hopeful defense of the seat. However, this seat also rocks forward and back, and seems unstable. None of those extra movements are intended.

"We could drill through here and add a bolt," Alexis suggests.

"That might keep it from moving this way," Mason says pushing the seat forward, "but it isn't going to fix this," he adds shaking the seat left and right.

"What if we tried...hmm," Cody, the original advocate for the swivel seat tries to come up with a solution.

After a few more moments of examining the seat, Alexis states, "I'll take care of it."

The day before Alpha

Tomorrow are the Alpha presentations in class. A few students are moving in and out of the bike lab but only to grab parts as needed and go to the fablab downstairs. I go to the fablab myself and see that I don't need to get someone to open the door because it has been propped open to accommodate the students moving in and out of it.

Much of Team Herding Cats are together and they seem to be putting a lot of energy into fabrication. Olivia comes out from behind the divider with a welding helmet propped on her head and a pair of gloves that are much too large for her grasping a freshly welded part.

"Make sure nobody touches this," she says to a tall, broad-chested team member standing next to the table where she places the part. Then she turns to another team member, "I'm ready for the part."

A student nearby teasingly asks the tall student guarding the still hot pieces of freshly welded steel, "why aren't you doing any welding?'

The tall student is annoyed at the seeming dig at his masculinity, "dude, Olivia's the better welder."

The student who just last week was trying to jump the queue to get a pair of tie rods for their bike machined walks by me.

"Did you get your tie rods?" I ask.

"Yes, one of the apprentices made them for me."

"No kidding?"

"Yeah, I offered to do his homework if he made them for us," the student says continuing on to the next task. I cannot tell if he is joking and I decide not to ask.

Olivia comes out from behind the divider to grab a steel tube.

"Hey Olivia, when you get a chance, can you take a look at this?" A Wednesday student addresses her.

"What do you want me to look at?"

"We want to weld this piece on but we're not sure if that's a good idea. Do you think this steel is too thin?"

Olivia tolerates this bit of side tracking and looks at the parts in question.

I note to the expert standing nearby that Olivia has really found her groove here in the fablab.

"She's great," the expert replies, "any mediocre man can do this work, but it takes a special lady to weld like that." I reply with a confused laugh as the expert heads back to their office nearby.

Behind the table to my left, Herding Cats is putting together what looks like a very complex pully system for propulsion. There are pieces everywhere. The bike doesn't look bad, well it doesn't look like a bike, it's a very different sort of vehicle than the others, but it looks intriguing. It has a long body that is low to the ground and handles connected to a pully, like a row machine.

"How does it work?" I ask.

"Simple really, you pull on this and it propels forward."

"It doesn't *look* simple," I think to myself. "How do you steer it?" I ask.

"It steers like a go cart, but the client just needs to lean to steer."

"Neat. Well I won't keep you from your work, it seems you have plenty to do."

"Yeah. The bike expert is coming in this afternoon and we're going to get some help with the propulsion. Hopefully get it moving a little smoother."

"Cool. Good luck!" I turn around to the other students in the fablab. I had seen Team Up & Down come in while I was talking, and I am eager to find out what is happening with the seat. It's almost surprising to see Doyle next to Jacob at the table in the rear, I'd grown accustomed to only seeing him in passing. At the other end of the table is a Sara weary looking.

I ask hesitantly, "how's it going?"

"Alphas are due tomorrow and we have to completely redo the seat, so not great."

"I'm sorry. What's up with the seat."

"There were still some issues with the swivel and Alexis says the client wants us to go with a stationary seat instead. So that's what we're working on."

I suspect from Sara's tone that she isn't satisfied that Alexis is truly speaking for the client on this topic. I've seen enough interactions between the students and client to know that Alexis very well could have said, "I think we should do a stationary seat," and if the client said that was fine it could be communicated as 'what the client wants.' Sara knows that too, but the bike needs a seat and there isn't much to be done about it except to put one on it.

"So how are you going to fabricate a seat."

"We're cutting the parts of Jacob's seat away from the swivel and using them to reconstruct a back rest for this seat," Sara explains pointing out the parts on the table.

Jacob holds up part of the seat, "so where does it need to be cut?'

Sara examines it and says, "here and here, no, here," and slides a hack saw down the table to Jacob.

"Oh, you want me to do it?" Jacob says looking down at the saw.

"Yeah, I'm going to get the bolts we never used, we can use them for this."

"I'll cut it," Doyle says reaching for the saw.

Sara tells them to clamp it down first before going upstairs to the bike lab. As Jacob and Doyle move a 'C' clamp this way and that, Alexis and Mason arrive in the fablab.

"How's it going?" I ask.

Alexis replies, "It's going fine," then pauses before adding, "can you tell that we're lying when we tell you we're fine?"

I give her a sympathetic smile, "yes, because grad students do it too."

Alexis volunteers that there's a problem with the brakes getting in the way of propulsion, or maybe it's the other way around. Whichever it is, they need to come up with a fix and they don't yet know how much they need to change to get it right. Then she turns her attention to Jacob and Doyle.

"What are you doing?"

"We're getting ready to cut this."

"Where?"

"Here."

"Stand aside," Alexis states and taking the saw tries cutting the part. It starts moving immediately so she stops to adjust the 'C' clamp.

"We tried that," Jacob says but Alexis didn't acknowledge him. Mason grabs another clamp and Alexis and Jacob work together to secure the awkwardly shaped piece.

"You should try clamping it to the other corner," Jacob offers.

"Yeah, I think clamping it to the other corner would work better," Doyle agrees.

"Clamping it to the other corner would make it more secure," Jacob continues.

"Guys!" Alexis replies impatiently, "corners are all the same." Alexis stares them down for a moment before grabbing the saw again and cutting. It's more secure but still wobbles back and forth some with each sawing motion. Jacob mumbles something and Alexis stops to ask, "do you have something to add?"

"No," replies Jacob sheepishly. He clearly didn't expect to be called out like that. I've noticed among numerous sophomore students that as the deadline draws close the tension they feel is coming out in their speech. Usually it's speech directed at someone who is not in the room, like a complaint about a team member who isn't giving enough

effort, but for a student like Alexis who isn't shy about how she feels, it also comes out to people's faces. While this is happening, Sara returns to the fablab. Seeing no need or room for another person to work on sawing apart the seat, she begins sorting the pieces already removed. Sara makes a small pile of parts that look like they can be reused and takes assorted bits to the trash can.

I check back in with Herding Cats and see them putting the pieces of their vehicle together. Two students are conversing about their work.

"That's it for the propulsion system."

"That's all the pieces for propulsion?"

"Yeah."

"Wasn't there supposed to be something here?"

"Was there?"

"I'm pretty sure there was another part that goes there."

"Well does the propulsion system work?"

"Let me try."

One of the men sits on the vehicle and pulls the handlebars connected to a cable.

Crack.

"Oh shit."

"What happened?"

"The seat just broke."

"Shit, really?"

"Oliviaaaa."

A confused Olivia makes her way to the beckon of her team. Behind me, Alexis is telling Hailey that she'll need to retrieve a part from their team locker. I hadn't seen Hailey come in and I want to catch up with her. Olivia comes over and examines the seat. She doesn't get excited about the broken seat but tells the team members what she can do to fix to it and when, as she's still working on other pieces. I head upstairs to see Hailey.

When I get to the bike lab I see Hailey standing in front of the locker and for a moment I wonder if she's forgotten what she's come in here for. Then I see her pull out her phone. When she grabs the lock and begins putting in the combination, only to pause and look back at her phone, it becomes obvious that she didn't know or had forgotten the combination. It's very telling, as no one who has been in the lab regularly has to fiddle with looking up the combination to their locker. Once the locker is open, she grabs a small plastic bag and heads back to the fab lab.

"How's it going?" I ask her in passing.

"Really well," she tells me.

I follow her downstairs again. As I head towards the stairwell, some members of Herding Cats are emerging from the elevator carrying their human-powered vehicle.

"Whatch'ya doing?" I ask.

"The bike expert is going to be here soon."

"Ah. Very good." I tell them as they hoist their vehicle into the bike lab.

The door is still propped open to the fablab when I get downstairs. "How's it going?" I ask Alexis.

"It hasn't gone to shit yet but it's not wonderful."

I can't stay much longer so I'll have to wait until tomorrow to see if and how everything comes together.

"You might want to stand back."

I turn around and try to quickly figure out if I'm in the way. Olivia is the person who just spoke to me and she nods her head towards the student that ended up behind me when I came into the lab.

"He's getting ready to cut that piece and he's known to be a bit reckless. But," she adds smiling, "he's a good team member, good team members can get away with being a little reckless." I thank her for the warning and give the reckless but appreciated member of Team Herding Cats more space to work as I take my leave of the fablab for the day.

Chapter Five: Resolution

Alpha Presentations

I'm filled with excitement and nervous anticipation as I head to the Design Studio where Team's Engaged, Up & Down, and Herding Cats will be giving their Alpha presentations this morning. Arriving at the room after many of the students, I make my way to the back and grab an extra chair from against the wall. Every person from the three teams appears to be present and the students are mostly sitting with their teams. Situated at one of the back tables is the bike expert with a legal pad and pen at the ready. By a wall near each team is their human-powered vehicle. Students are adjusting their bikes, looking over presentation slides, and shuffling notes.

I'm sitting behind Team Up & Down and lean forward to ask Mateo, "How did the rest of fabrication go?"

"Good, bad, good, bad, good."

"At least it ended on a high note."

Mateo and Mason exchange glances, shake their heads at me and respond with "Ehhh." Mateo adds, "It's in the middle, but there were a lot of highs and lows in the process."

After a brief introduction it's time for presentations. Team Up & Down opts to go first. Alexis begins the presentation by showing a video of the systems working on their bike. She talks about how the systems work together. She turns the presentation over to Mateo who, showing the CAD model, describes changes that have been made from their design at the beginning of the semester to the vehicle now; this includes the addition of a

chest rest, changing the seat, and modifying the frame as necessary in response to demonstrated need for more support. Jacob takes over the presentation and goes over the specifications they settled on at the beginning of the semester clarifying which they've met at this point. The PowerPoint switches to the next slide and Mason steps forward to talk about problems and possibilities. They recognize that the bike is difficult for the client to get on and off of and need to adjust the angle of the seat. Additionally, there are safety issues to address for the beta prototype. Cody takes over for the next PowerPoint slide which is a chart of numbers. He lightens the mood, in true Cody fashion by making a quip about how the bike is surprisingly fast. He then goes on to explain that they took the bike outside and tested how quickly they could stop the bike and something about the gears that I don't quite grasp. That's what the table of numbers is, the results of these tests. Sara wraps up the presentation describing the plan of action for moving from the alpha to the beta prototype. The students remain up front waiting for the professor's feedback.

"The presentation was good, good movement through the slides," the professor says, "but I want to know more about the rationale for changes. As a designer, you had a reason for the other design, there has to be engineering and design reasons behind the decisions you make, how do these changes impact the rest of the design?"

Alexis and Cody explain a few of the changes they made along the way. Jacob adds that they thought they would be able to buy more parts after the bill of materials but that wasn't the case. I'm not surprised to hear this complaint worked into the conversation.

It's time for the team to demonstrate functionality. The professor tells them to move the bike to the far side of the room, pedal it to the student sitting on the other side, then brake. Because they have two propulsion systems and two braking systems, they'll have to do this twice. The first thing that happens when they move their bike is that the brake line gets stuck on a handle.

"Take your time," the professor says in response to them awkwardly moving the bike around up front. With more intentional movements, Cody and Mason position the bike on one side. Sara gets on the bike. I'm sure choosing Sara to demonstrate the bike is related to her height which is closest to the client's. I've seen numerous times that when the students don't have the client available to test their bikes that they'll have the teammate they think matches the client's body the best get on it. Two times Sara propels herself across the room and brakes. It's great to see all the systems functioning. The professor has questions about the way the handlebars are positioned and asks the bike expert what they think.

"I have a lot to say, I'll wait until you're finished," the bike expert says to the professor. After a few more questions, the professor turns it over to the bike expert. The bike expert addresses the brake line getting caught in the handlebars and tells them they need better cable management. Then, explaining to the class how safety inspections will be conducted, begins addressing the things Team Up & Down will need to work on before their bike will be ready to pass inspection—plugs on the handlebars, Velcro strap on the brakes for stability getting on and off, chain guards, and a few other items. It sounds like they'll have plenty to get done in the two weeks until beta prototypes are due. The bike expert gives Team Up & Down some ideas for combining solutions for the list

of problems they need to address. For example, they can make a chain guard that is also a step to make getting on and off the bike easier.

"Okay, who's next?" the professor asks. Team Engaged rises from their seats.

They're bike is shaped a bit differently than the Up & Down bike, the frame is larger and rectangular, but like Team Up & Down it has two propulsion systems, one operated with the hands and the other with the feet. The team moves systematically through an explanation of concept generation, testing, fabrication, and more testing. Like before the professor has questions and the bike expert talks about improvements that are needed for safety, Before dismissing this team, the bike expert makes some suggestions, "The client has more upper body strength than lower body strength, consider using a lower gear for ease of getting started."

It's Team Herding Cats turn. I shift in my seat as two members of the team hoist the human-powered vehicle from either end and bring it to the front of the room. A little more than half of the students standing up front have been present at all in the fabrication spaces, and only three of them with any kind of regularity, and those three have only been in the fabrication spaces towards the end of the build phase. Team Engaged also only had half their members regularly in the fablab, but they were busy from the first day after spring break and appear to be well-supported by the rest of their team.

A young man starts the presentation describing changes that have occurred from the preliminary design until now. This must be the project manager I heard hasn't been doing anything.

"The design changed from four wheels to three wheels, then from delta to tadpole design, we've made changes to the frame…" I make a note that they've had a lot of changes.

Olivia takes over the presentation, "here's a video of us demonstrating steering, we had everything together in this video, but the bike broke in the video."

The professor, in a comical display of exasperation, puts their forehead down on the table.

"This all happened last night, it was together but when we went to take a video it fell apart."

The professor asks for more information and one of the team members makes a bold choice, "the derailer wasn't designed to withstand that kind of pressure, but we built something to replace it. It's very sturdy now. We just need to put it back together."

It's a bold choice because they added a derailer at the suggestion of the bike expert who spent hours the day before with the team trying to help them get it functioning.

"Tell me what you've learned about manufacturing," the professor says to the team.

Olivia answers, "we learned that our proof of concepts were lacking."

"Carry that with you," the professor replies, "I don't know how many capstone teams I see punt and punt and then have a pile of parts at the end of it. It came together this time, but this was a relatively easy task compared to what you'll be doing for capstone."

Before the professor dismisses the students, they emphasize again that they will not get to present their bikes at the final presentations if they don't pass the safety inspection and will receive a zero for their beta prototype. The next topic to discuss is the upcoming FabCon. Every member of every team is required to attend. The students will have to go early to set up and take a group selfie to show that everyone was there. I've heard about FabCon a few times. One senior expressed that when they went as a first-year student, they only had a dinky project to show, a project that no one cared about or wanted to see, but now they are one of the seniors with a cool capstone project to show off. The professor goes on to explain, "you can have a poster at your spot, but it isn't required. You're required to be at FabCon, but you aren't graded for what you show there. I don't care if you bring a box of parts to FabCon."

The last thing I do before leaving is wish Olivia good luck with the project. Team Herding Cats' presentation was a bit of a train wreck and I wonder to myself if there is any other team among the sophomores who is having such a time getting their project together.

On my way to the research lab I see a sophomore student from another section in the hall. "Hi, how's it going?"

"It's going."

"Is your Alpha presentation today or tomorrow?"

"It's today, in a couple of hours."

"How are you feeling about it?"

"I feel…tired. I was up until 4am and things kept going wrong with some key pieces of our bike… and then, it literally caught on fire."

"Dear god," I gasp, "that sounds awful." I decide to rearrange my day so I can be at their presentation this afternoon.

Between Alpha and Beta

I'm tired. The end of the semester is brutal for first year graduate students and Sophomore engineering students alike. While the Sophomore students are working to pull together their betas and make sure they can pass the safety check, I'm pulling together term papers and other assignments for my courses. I still try to observe them when I can but between studying for finals and working on projects for other courses, the Sophomore students just haven't been in the labs as much. Often, the fabrication spaces don't have a single sophomore working. The bike expert is conducting safety inspections so there are students around here and there making improvements on their bikes but it's nothing like the flurry of activity right before the alphas were due. I force myself to stand up from the table in the research lab so I can go peak into the bike lab.

I've only emerged from the office when I hear a voice to my left shouting to me from the end of the hall. Startled, I turn and see the client on Team Up & Down's bike. Their eyes are as wide as their smile as they propel themselves in my direction. Behind the client, Cody is jogging up the hall to catch up. "We're moving now!" the client calls out from the bike as they move past me. I laugh out loud. Grad school is hard, but this moment is a beautiful respite from an otherwise dreary and exhausting week.

"The bike looks great!" I call out to Cody who pauses momentarily to smile and nod before jogging on after the client. I've gone from tired and glum to energized by the sight of the client clearly having a great time and Cody chasing behind them. I laugh again head for the bike lab too.

In the bike lab, Cody and the client are talking about the bike and what might improvements can be made to make it operate more smoothly. They chat until the client needs to leave. When the client leaves, Cody does too, leaving me to look around at the bikes that are transitioning from alpha prototypes to beta prototypes.

I go to the spot where Team Engaged's bike usually stands, but it's not there. Looking down I gasp when I see a large carboard box with so many pieces of steel tube in it. "Oh my god, I cannot believe they are actually bringing a box of parts to FabCon!" I say aloud to no one. I heard the professor say that was an option, but I did *not* expect anyone to take them up on it. Still shaking my head in disbelief, I go look at the other teams' projects.

Somewhere on each table is a piece of paper taped in place with the bike expert's handwriting on it. It's a list from previous inspections of what still needs work. Some lists are short, others long. I wander around the room reading the lists. Team Up & Down looks like they're almost done. There are just a few items on the list, some sharp edges that need to be filed down and a couple of spots where a finger could get pinched. Team Herding Cat's list is long, but that doesn't surprise me. Last I saw them they were still trying to get their propulsion system working again, so I doubt they've even moved on to the safety stuff. Before I go, one of the Wednesday students comes in and grabs a toolbox from a locker. They are kneeling next to their bike when I ask them what they are up to.

"There's some things I want to work on before FabCon."

"I heard the professor say that it wouldn't matter if you brought a box of parts to FabCon," I say, looking over the student at the box of parts across the room.

"I know, but I'd really like to be able to show off our project to my family. They're driving two hours to come see it this weekend."

* * *

The professor mentioned to me that FabCon is a family friendly event, so I brought my whole family. FabCon started early in the day, but I opted to show up later. My toddler begins this adventure being adorable and my preschooler is interested in everything going on, and there's food; I'm sure they'll be fine. As suggested, the senior capstone projects are front and center. I'm having a delightful time saying hello to people as I make my way down the hall. Moving past the capstone projects, I get to a section of hallway with all the human-powered vehicles. Each vehicle has a collection of well-dressed team members hanging out by it. As people move through the space, the students are ready to answer questions about their bike. I see some students with their parents and others hanging out with peers. It looks like the students are taking turns being stationed at the project.

They didn't need a poster, but all teams except one have them anyway. The posters pull images that have been used for previous assignments and include a few paragraphs that talk about design, the client, and the team's processes. There is nothing about what is on display that reveals bikes falling apart the day they're due or building tension between team members.

Moving from one bike to the next, I was shocked to see Team Engaged's bike, fully fabricated, just sitting there as if it hadn't been a box of parts very recently.

"Michael, I don't understand! It looked like your team was going to bring a box of parts to FabCon."

"Huh?" Michael clearly hasn't been following the saga of the cardboard box that has been playing out in my head, but he catches on. "Oh! Yeah, no, we rewelded the frame. Took a foot off the length and lowered it."

"Wow!"

"Yup, it's lighter and easier for the client to get on and off of."

Moving further down the hall I see a ribbon next to Team Herding Cats poster. "What's this?" I ask the student sitting nearest their poster.

"People's choice award. Our project is being recognized for getting the most votes among guests."

"Really? Okay, congratulations," I say with surprise. I guess I shouldn't be too surprised, it does look interesting. It wasn't operational the last time I saw it, but you wouldn't know that by just looking at it, and it's not like other teams aren't facing their fair share of problems. Furthermore, the dysfunction of the team isn't visible in their lovely display. I ask this student, "is the project manager here today?"

"That's me. I'm the project manager," the student says with a smile.

My head is reeling. If that's the project manager, then who was that other student? If I was wrong about this, how many other things have I been wrong about? Was this person even at the alpha presentation? They don't look familiar, but I'm not sure. I don't bother to explain that I'm a researcher observing the sophomore students on the bike project. This is the first conversation I've had with this student and it's a week away from the end of the semester. I walk away feeling unsure of myself as a researcher.

Some members of Up & Down are posing for a picture in front of their bike. "Looks good," I say to Jacob.

"Thanks. Herding Cats got the people's choice award, but that's only because Jon sent his little brother around to tell everyone to vote for them."

I laugh, at the revelation and at Jacob leading out with that.

My toddler has gone from cute to restless and my preschooler from interested to bored. I try to see as many displays as I can as my family winds through the crowd on our way out.

* * *

It's the last week of the semester. When I talk to students they tell me about their summer plans. Several students have told me about internships, some have mentioned travel plans. The final presentations are coming up and the students still have some work to do, but that work has been overshadowed by studying for and taking final exams. I also suspect that showing the projects off at FabCon has created a false sense of completion. I noticed a few students in the bike lab though, so I grab my safety glasses from the research lab and join them.

"You can eat your banana in here," Mason is telling another student as I come in. It sticks out to me as a contrast to the hesitancy another student had early in the semester about bending the no eating rule. I see Mason dig into his bag and take out a pack of crackers which emphasizes his point.

I approach a Wednesday student and ask what they're working on. He holds up a disk-shaped bicycle part with bearings inside. "When we welded the tensioner on, the heat distorted this, I'm trying to replace it."

"Bummer."

"Yeah, fix one thing, another thing breaks."

Olivia from Herding Cats, Jacob, Alexis enter the bike lab. Alexis goes straight to Mason to check in. Olivia slides down the wall and stays there in a slump.

"You okay?" I ask her.

"I haven't slept more than a few hours in the last several days and I think I just failed my Statics and Dynamics final."

"Oh no, hopefully you didn't do too bad," I try to offer some sympathy and encouragement, but her face says she already knows it's as bad as she fears.

The Day Before Final Presentations

Final presentations are tomorrow. I saw some pretty lengthy laundry lists of tasks to accomplish from the bike expert. The professor reiterated, again, in class on Tuesday that this afternoon was going to be the last safety check and they all needed to pass it to present their project. The bike lab doesn't have much activity, so I check downstairs in the fablab. I can see through the large windowpanes before I even get to the lab that this is where the sophomores have congregated. As I get to the door I see a sign, "Do NOT prop doors. Anyone who props a door open will have their access revoked!" The students have been bending the rules more and more towards the end of the project, but it seems there are some rules that are non-negotiable. I tap on the glass and the expert opens the door for me.

"Busy in here this afternoon," I say.

"The fablab is usually closed this week to give all of the student employees time to study for finals," the expert tells me as we look over the wood shop where members of Teams Engaged, Up & Down, and Herding Cats have a couple of students moving about with intention. "I had to put out a call to the student employees for volunteers to work

this week," the expert continues, "only one answered." The expert gestures across the lab to a tall upperclassman. The student employee has his arms crossed in front of him as he silently watches the Sophomores grabbing tools, working on parts, grabbing more tools, and continuing their work. He wears safety glasses, an apron, and an unamused glare. Pleased or not, he's here; if he weren't these students would be up a creek without a drill press. The expert states, "they have until he leaves at 3pm, then they've got to clear out," and adding as an afterthought, "you should put the lack of communication from the people upstairs with the people downstairs in your research."

Two worktables stand side by side with a member of Team Engaged drilling into a piece of metal at one, and a member of Team Herding Cats using a hacksaw at the other. Two students, backs to each other, hard at work. One has dealt with missing members throughout the semester and has struggled because of it. The other is from a team that has stayed ahead of most the others. Team Engaged's comparably simple design, skilled and reliable members, and ability to work well together has propelled them forward this semester. And yet, here they both are—the team that has barely gotten by all semester and the team that has been ahead of the curve—both struggling to finish their work in time for the pass or fail safety check.

As I ponder this and other observations, something strikes me. It becomes clear so suddenly that I find myself startled. How did I not see this coming? When did it happen? Looking around at the students working, I see people moving through the space with confidence and competence. There is none of the hesitation before a cabinet full of tools that I had observed earlier in the semester. They know what tool they need, where to find it, and how to use it. I see students who don't need someone to reassure them that they're

on the right track, because they already know. The change happened subtly, over time, but is no less remarkable when I think back to how some of these same students navigated these spaces less than two months ago. Not everyone has had the same benefit of developing expertise though, because not everyone has been here putting in the work.

"We could use shears," the student I now know is the project manager from Team Herding Cats suggests. Someone tells him that there are none in the fablab, and I see someone from Team Engaged glance at Olivia. The project manager from Team Herding Cats doesn't realize that he has embarrassed himself by loudly suggesting his team use a tool that isn't even available. At the beginning of the semester, those other students might not have known that either, but this isn't the beginning of the semester. While this student was doing other things in other places, many of the students present in the fablab today have been learning what is available, where to find it, and when to use it.

I'm watching Team Herding Cats struggling to use a drill with a flat bit to do the work that shears may have also been able to accomplish. Suddenly, the student employee walks up and takes the drill out of the team member's hand. He doesn't say a word. He takes the bit, puts the drill on the table and walks behind the partition. The members of Team Herding Cats and I stand there dumbfounded. Did they do something wrong? The sound of the metal sander spinning up on the other side of the partition removes the uncertainty from the situation. I feel a sense of relief and I think I can see relief on the faces of the Sophomores who still don't dare speak. Moments later the student employee emerges from behind the partition with the freshly sharpened bit which he puts back in the drill and hands to the Sophomore. It works beautifully. The Sophomore with the drill offers a meek smile to the student employee who returns a sober nod.

As the students continue to work, I keep an eye on the time. Forty-five minutes until the fablab closes. Mason and Mateo are filing some sharp edges on the frame. Someone on Team Engaged has fabricated a chain guard and is smoothing the edges on that. Team Herding Cats has part of their bike disassembled. Thirty minutes until the fablab closes. Students are moving faster around the room and the tension is palpable. They know that once the student employee calls it, there will be no negotiating. This student has been incredibly helpful to the Sophomores both today and many times previously, but his crossed arms, straight posture, and set jaw dare anyone to ask for more than what they've been generously given by him being present in the space. The Sophomores shuttle quickly across the space in front of his hard gaze moving back and forth between tool cabinets and worktables. Fifteen minutes until the fablab closes. The student employee speaks.

"Time to clean up." The privilege of using the fablab includes the responsibility to clean up after yourself. I notice that at first the Sophomores keep working, but as the minutes tick away, they divide their duties. On Team Up & Down, Mason is trying to finish the piece he was working on while Mateo puts away tools and grabs a broom which he keeps ready for when Mason is done. Bit by bit, students switch from working to cleaning until almost everyone is pitching in. On Team Herding Cats, they are gathering their bike with some parts and heading to the elevator to get everything back in the bike lab. Shortly, the bike expert will come and do final safety checks.

Final Presentations

Most of the department is empty, most of the engineering students have already wrapped up all their coursework, completed their finals, and are gone for the summer.

Some are heading off to internships, some are traveling, some are happy just to go home. The Sophomores are all here though. Today is the final presentation; it's the last thing most of them have to do before they too can leave for the summer too. There are nine teams in the Sophomore cohort, but I have no idea how many of them have passed the final safety check to be able to present today. Students are moving in and out of the lecture hall where the final presentations will take place in about 20 minutes. The client and the client's family and friends are here too. The bike expert is here as well, and I navigate past the others to ask them how the final safety checks went.

"I just finished the last safety check," the bike expert tells me. It was stated repeatedly that yesterday's check would be the last chance students have to pass safety checks, but I'm not surprised the bike expert has gone out of their way to get every single team across the finish line. We keep chatting and they tell me that they stayed until 9pm last night and three teams still hadn't passed but came back today to finish safety checks.

"I really like working with the students," the bike expert tells me, "the bike industry is entrenched into certain ways of thinking and problem solving, the students come up with creative solutions that would never occur to those within the industry." Perhaps recognizing that not all the student's creative solutions have worked out very well, the bike expert adds, "I tell them to keep it simple; keep it simple, but not too simple, that's from Albert Einstein." While we wait, the bike expert tells me about creative solutions the students have come up with over the years.

When it's time for the final presentations, the client is seated front and center. The professor uses the introduction as an opportunity to recognize how much hard work the students have put into this project and thank them for that work. One by one, the teams of

students file to the front from the left with their human-powered vehicle, give a three to five minute presentation, pose for a picture with their project then file off to the right as the next team gets into position behind them. There are nine teams and after the presentations everyone will go outside so the client can test each team's bike, so the goal is to keep things moving.

The presentations are brief and different in tone than the ones that occurred in class. Instead of going into a lot of detail about fabrication or design, the students address the needs of the client and why their project is appropriate to meet those needs. One team stands up and invites us to imagine a future for the client in which they can go bicycle riding with their growing child. It strikes me as a bit cheesy, but I look over at the client and they seem into it. One team declares that the client said they wanted to push themselves, so that's why they stuck with a lower propulsion system. I smile at the bits of justification that are woven into these brief presentations. Every team highlights safety and the client's desires as the guidance for their decisions along the way. There's a quote from Susan B. Anthony and another from James Finch sprinkled in.

Since the presentations are short, only one or two team members speak for the rest of the team. On Team Engaged the project manager connects their rationale to design elements on the bike and notes that as often as possible they relied on commonly used bicycles system which kept their design simple and reliable. When it is Team Up & Down's turn, Alexis explains the difference between a bike and a human-powered vehicle describing the latter as being especially joyful because of what it can accomplish. Mason then explains some of the design choices they made along the way. When it is Team Herding Cat's turn, one of the members describes their human-powered vehicle as

intricate and unique as selling points. "We created the bike that we think is perfect for our client."

Everyone moves outside for the testing of the human-powered vehicles. There's a flat area out front with plenty of room for everyone to gather around. The client has donned a helmet and will take each human-powered vehicle for a spin around the area where everyone is gathered.

"Hey," Cody gets my attention while the crowd is getting situated, "this is my mom."

"Nice to meet you!" I greet Cody's mom and tell her what a pleasure it has been this semester to observe Cody's work on the project. "Cody has done excellent work in the shop getting his team's bike together."

"Thank you," Cody's mom smiles at me, "we're proud of him."

Just beyond a group of students, the client is getting on Team Engaged's human-powered vehicle. Like Michael had mentioned, rewelding the frame made it easier for the client to get onto. As the client starts pulling away from the team it is apparent that they are struggling to use both propulsions systems simultaneously. After a bit they just use the upper propulsion system, but it works well to get the client out and back to the students.

"Great job, guys!" the client tells Team Engaged.

The client is struggling to get on Team Up & Down's bike, but Mason and Cody hold it in place and help the client onto it. The client gets going without trouble, but a strap on a pedal breaks about 20 feet from where they started. Mason jogs over and helps

the client get their foot positioned on the pedal. There's nothing that can be done to fix the strap now, but the client is still able to complete the test drive pedaling carefully.

"We can fix that strap," Mason says.

The client says, "no problem, great work."

Team Herding Cats roles their human-powered vehicle over to the client who carefully lowers themselves onto it with the help of Olivia and another student. The vehicle immediately tips over spilling the client onto the ground but students scramble to help the client and the vehicle back up. The propulsion is difficult to use, but the good-natured client exhausts themselves taking the vehicle out and back. A student follows alongside in case there is another spill. The client pauses halfway to catch their breath but doesn't complain. When they get back the students help them back up and the client declares with a smile, "wow, that's a GREAT workout!"

The client is kind and goes out of their way to help students save face if things don't quite go as planned. The brakes were hard to use on one vehicle and the client almost ran into a small child, but when they got off the bike they told the team everything they liked about it. One bike was too difficult to pedal forwards, so the client pedaled it backwards out and back again complimenting the students for how well it moved backwards. There were two vehicles with motor assist, one that worked and sent the client zooming in several wide circles at speeds that left me feeling nervous. The client was having fun though and took it for a couple extra spins around the crowd. The team whose motor had caught fire just before the alpha presentation still doesn't have a working motor today, but the client compliments them for how comfortable the frame and seat are.

I notice Michael taking pictures of the client using each human-powered vehicle. When I ask him about it, he explains that he has been hired to fabricate the final product for the client over the summer.

"Whoa, cool! Way to go."

"The client will let me know later which design elements they preferred, and I'll pull them together for the final product," Michael explains.

"Ouch, dammit." Behind me someone tried Team Herding Cat's vehicle. It broke.

The client looks a bit winded after trying all nine human-powered vehicles, but asks the students to gather around after the last ride. The students create a crowd around the client and lean in listening. The client begins to address the students but pauses being overwhelmed with emotion. Everyone stays frozen and the only sound to be heard is of birds and a few distant cars. When the client is able to continue, their voice cracks as they speak.

"I want to be an example for my daughter, and I can't do that from the sidelines. I want to be with her when she learns how to ride a bike, not watching her pedal away from me from my porch. To be able to move like I did today is a gift, and you did that. You did that for me. Thank you."

After a group picture the students, experts, client, and family members slowly disperse. I make a note that the students are walking away a little bit taller with their heads held high.

Fall, 2019

I worked on campus some over the summer. Not a lot, but I was hoping to catch up on things I didn't accomplish as a paid research assistant the previous year, and get a head start on the work that would be accelerating with the return of students.

There weren't many people here over the summer. Olivia did fail Statics and Dynamics, so she was here taking the course over, along with several other sophomores. I've gotten to know Olivia better over the summer as she occasionally stops in for a conversation in the research lab. Michael worked several days a week designing and fabricating the human-powered vehicle, but it isn't finished yet. Not surprisingly, the final design is a lot like the design of Team Engaged's bike with some modifications. All in all, it was pretty quiet over the summer, which is why I'm grumbling under my breath as I avoid hitting students with my car and searching for a parking space.

Today is the first day of Junior Design and I'm eager to see all the students (and see who got the official letter of invitation into the program). I've already checked with the professors co-teaching the class to make sure it's okay for me to join them. Unlike Sophomore Design that is divided into so many sections, the entire junior cohort goes to Design together. However, in a manner of weeks they will divide up into their capstone teams and will once again be working in a small group. These are groups they have some say in forming though and conversations with a few students over the summer indicate that many juniors go into this year already thinking through their options.

When I get to the large space used for Junior Design, there are only a dozen students in the room because it's still early. My face lights up when I see Sara across the room, and I head straight over there. We exchange happy greetings and I ask her about

her summer. She tells me about her travels. I tell her that I'm so glad to see her in class and ask her if I can capture a few thoughts from her in my notebook about transitioning from the sophomore year to the junior year.

She agrees and leads with, "I'm glad to be here, but.."

"But what?"

"I don't know, I just can't seem to get it right."

"What do you mean?? You're here aren't you? You passed all your classes to get here."

"Yeah, but the seat I built didn't work."

"Does that matter? You managed to pull something together and complete the project."

"The instrument I made in my first year didn't work either."

"Oh. But you're a great student, and things fall apart sometimes," I try to reassure her.

"I'm just not the engineer I want to be," she tells me. "I'm going to take a role in a capstone project that won't leave anyone relying on my design skills."

I feel so disappointed that Sara has internalized her experiences this way and try to remind her of all the things she's doing well. There are other students who have struggled every step of the way but seem to move on from those setbacks with fewer blows to their self-esteem. If only Sara's definition of engineer wasn't so tied up in her ability to fabricate something new. I know she's excelled in most of her classes, I know she's talented, why doesn't she see that about herself? As more students file in the room

and greet each other warmly our conversation turns to who made it through and who didn't.

"We had three members of our team not pass."

"Hailey and Doyle?" I ask.

"Hailey and Doyle," Sara confirms.

Before she has a chance to tell me more, I ask her, "do you think if Hailey and Doyle had been more helpful on your subteam, that would have made a difference in how the seat turned out?"

"Maybe, I took the lead on the seat though, so I should have been telling them what I needed them to do."

"Is that what you do?"

"What?"

"Do you sit around waiting for someone to tell you what to do?"

Appalled at the suggestion Sara answers, "no."

"Well okay then."

"Point taken."

"Wait," I ask, "who else didn't pass on your team?" Hailey and Doyle broke what I now realize is a cardinal sin in the engineering department, they left their team hanging when their help was needed. Everyone else on the team though, they worked hard to get the project completed.

"Cody," Sara answers.

"WHAT? Cody didn't pass? Are you kidding me?!"

"Nope, turns out he didn't turn in a single individual assignment."

"Oh, Cody, nooo." I can't believe it. Cody was instrumental in the fabrication of their human-powered vehicle. "Why, Cody, why?"

"I was shocked too," Sara admits.

"But everyone else made through?" I realize I can take nothing for granted. I thought I had an idea of who would be here and who would not based on the students' level of engagement on their teams, but clearly that is not as reliable a determinant as I thought. It's not a bad measure though, I realize as I look around the almost full room and can't spot several people from Team Herding Cats.

"Everyone else on the team should be here," Sara tells me, "I think Alexis is going to propose her own project for capstone."

It's time for class to begin so I find a seat and hang out. The class addresses creating a persona, empathizing with a client, finding the pain point, and coming up with appropriate solutions. Sounds familiar. The students work through small group activities demonstrating their mastery of this process. I walk around as they do, observe, say hello, listen in to the conversations.

Spring 2020

The bike project has changed a lot this year making my thesis a snapshot of the project frozen in time. Even with the changes to the structure of the project there are similarities that confirm my emerging sense of what the bike project is and does. I don't go to many of the sophomore classes though. I've been advised that I have enough data and I don't need to keep gathering more. I like gathering data though, and there's always more to see and know. So every now and then, I take my leave of the research lab that is now covered in my scraps of paper and white boards that I've scrawled all over, and head

to the Sophomore Design Studio. I know the students have been grouped into teams at this point, but I haven't been to a class yet since the start of the spring semester and I'm eager to peek at the team dynamics.

I go downstairs first to get some coffee, coffee that I will need later to fuel my ongoing analysis and writing. When I get downstairs I peer into the makerspace with all the 3d printers. Mateo and Mason are in there and I tap on the glass and wave. They both ended up on a capstone making a fuel-efficient vehicle. Mateo smiles and waves back, Mason nods. Mason still isn't much for conversation with me. One time I wandered into that makerspace, where he spends most of his time, and asked a question about printing bumper stickers. Well it just so happened that Mason helped fix the machine that does that and my goodness, he talked to me more in that ten minutes than he had his entire sophomore year. That's why I always swing by this space now. "Tell me the secrets of your MAGA sticker, Mason," I think to myself. As I'm standing there I notice the student on the other side of Mason has a large "Guns Save Lives" sticker on his laptop. Different groups of students gravitate to different spaces in the department.

I grab some coffee and as I do I see a familiar student getting a snack. It takes me a moment to realize it's the Jewish student I met my first semester here. I saw them in passing only throughout the project. His team seemed to struggle at final presentation, but he had been there. It occurs to me that I hadn't seen him in Junior Design.

"Hey," I address him.

"Oh, hello."

"How are you? I haven't seen you around the engineering department."

"I switched to a physics last semester."

"Oh? What prompted that."

"I had thought about it before, and then when I didn't pass Design that sealed the deal."

"How's it going in the physics department?"

"Great, I'm good at it and the community is nicer."

"What do you mean?"

"In engineering, if you need help, no one wants to give you the time of day. In the physics department the people are friendly and helpful. I just fit in better in the physics department, there aren't so many dudebros there."

This student's words linger with me as I go back upstairs and join the sophomores. I go in the familiar studio and say hello to a few students I met last semester. I hadn't been in since the new semester so there are some new faces in the room and…

"What?!" I traverse the room to get close to a familiar face that I did *not* expect to see today. "Cody!" Dropping formalities, I give Cody a hug. "You're back!"

Cody laughs, "yup, I am *going* to finish this engineering degree one way or another!"

I wasn't sure if the students who failed Design II needed to restart at Design I or if they could just start again with II. I guess I have my answer. "So what happened?" I ask Cody.

Cody tells me that he was close to the cutoff for getting credit for this class and he went to the professor, but the professor wouldn't budge on the issue. He was mad that the

professor wouldn't give him the couple of points needed to pass, he even tried going to the head of the department to no avail.

"But you're back now," I say, "and I bet your team will be glad for your help this semester."

Cody hopes so but notes again that the professor shouldn't have been so stubborn about those couple of points because Cody had done so much work on the team's bike. "That why I'm taking *this* section," Cody tells me nodding towards the professor that is decidedly not the professor that wouldn't pass him last time.

"Well, I'm happy to see you back." I tell him and go find a seat for class. Surprises abound as Hailey comes in too! I let Hailey know that I am glad to see her, and she tells me that she is trying to take her work more seriously this time around and is getting more engaged in the department.

"I even joined the engineering outreach program," she tells me.

* * *

I picked up my son from daycare and brought him back to the engineering department with me. The sophomores are gathering in the bike lab to present their preliminary designs to the client. I missed this last year and want to see it for myself. Keeping my toddler strapped in his seat I roll him around the tables and look at the posters made by the students showing off their designs. The students have prepared 'elevator' pitches for their projects. The client goes from table to table listening to the students. The professors also go and listen to each pitch marking an evaluation form. Some juniors come in including Olivia, and Michael. They grab evaluation forms of their own and make their way around the room listening to the students and offering feedback.

As I approach the tables the students begin their spiels for me, I'm not evaluating them, but they don't know that.

Crossing paths with the professor I mention how nice it is to have some of the juniors here offering the sophomores guidance and helping with evaluations. "Do they get extra credit for this?" I ask.

"No," the professor replies, "we tell them when it's happening, and they show up."

I smile at the juniors moving around the room.

Olivia cocks her head to one side as she examines a sophomore's sketch. "Let me tell what you're going to run into if you try to weld your bike this way."

Chapter Six: Interpretations and Discussion

The sophomore engineering students at State U are engaged in a series of negotiations. They are negotiating their membership in the program, their roles in groups, and their professional identities, all while developing engineering expertise. As the undergraduate students go about their daily activities in the engineering department, their primary concern is completing the tasks ahead of them so they will progress through the program. This is intensified by time constraints and complicated by exploring opportunities outside the department (such as internships and extracurricular activities) as students connect what they are doing for their classes to what they could be doing when their time at State U is complete. For sophomores, completing these tasks takes on the added value and pressure of legitimization in the program in the form of an invitation received over the summer between sophomore and junior year. At the epicenter of these negotiations are the courses Design I and II, and the team based making project, "the bike project." To explore the intersections of learning and membership negotiation in these contexts, this chapter explicitly examines how the narratives in the prior chapters illuminate an understanding of the following two research questions:

RQ1: What are the characteristics of learning in a team centered making project (i.e. "the bike project")?

RQ2: How do students negotiate their membership in an engineering department during a team centered making project (i.e. "the bike project")?

A simple and succinct answer to the first research question is, *learning in the bike project is characterized by sensemaking within units of coorientation*. Below I offer an expansive interpretation of this finding by first examining sensemaking at every stage of

the project, followed by observations of how the teams (units of coorientation) impacted learning. Further, a concise answer to the second research question is, *membership negotiation is characterized by adequate fulfillment of requirements and finding one's place in the community by negotiating with the values of the department*. The following sections elaborate and examine these processes in the conversation with the scholarly literature on learning and organizing.

The Characteristics of Learning in Bike Project

Learning in the bike project is characterized by sensemaking within units of coorientation. Sensemaking is noticing and interpreting relevant information to enact organization, like the organizing of bicycle parts into a human-powered vehicle or the organizing of a narrative that is presented at the end of the project. A unit of coorientation is a pair or group of people focusing on each other and the task at hand as they work together to accomplish their goals.

Making Sense of the Bike Project

The learning that occurs in each stage of the bike project can be understood through the framework provided by sensemaking. Like a narrative that can be parsed into distinctive phases, each serving particular purposes, the bike project also had distinctive phases. In the first part of the project, the exposition portion, learning is characterized by 'sensegiving.' That is, interpretations of available information were presented to the students to steer the way they organized their projects. In the action part of the story, mediated sensemaking takes the fore. Mediated sensemaking is the disruption of sensemaking to obtain better outcomes. It manifested in the action portion of the project as questions and guidance from the professors and other experts. In the resolution part of

the story, the students must make their own sense of the project and present their interpretations as reports and presentations. In constructing their interpretations of events, students find positions in an emergent community and further the process of developing a professional engineering identity.

Sensegiving

> "I chose this school because it's hands on, I didn't want to just sit through classes for four years." – a student reflecting on their choice to attend State U

> "I wish I had more time to teach this to you because I'm about to confuse you badly with this next topic." – the bike expert moving quickly from one topic to the next during the bike breakdown activity

Sensegiving steers the sensemaking of students through provided interpretations. Sensegiving includes vision-casting, communicating 'correct' definitions, and infusing efforts with energy through engaging communication (Gioia & Chittipeddi, 1991). The first semester of the bike project, and part of the second, are characterized by professor provided interpretations of the project. Efforts to hand 'sensemaking' over to the students, so they can arrive at these interpretations themselves may be frustrated by a lack of mindful engagement and more pressing demands on the students' attention.

The professors provide interpretations in the form of definitions. They define the project, its objectives, and the processes necessary to meet those objectives. Objectives are communicated through the syllabus, written instructions, and in-class directives. Design I and II are process oriented and the students learn from their professors a process for everything from identifying stakeholders near the beginning of the project to selecting

parts for sustainability near the end of the project. The amount of time spent defining processes violates the expectations of students who understand the project first and foremost as a fabrication project, as opposed to a design project.

The professors engage in sensegiving when they promote their interpretation of the bike project's ***meaning***. The bike project holds meaning for the students from the first time the students hear about it. For some, it's an opportunity to *fabricate something new and innovative*. This was evidenced in the conversations that popped up even early in the first semester when one student would turn to another between in class activities and suggest novel ways of constructing the human-powered vehicle. For other students, the meaning of the project relates to *feelings of apprehension* over the scope of the project. This was apparent when I spoke to the most recent group of sophomores outside the studio before their first day of class during the fall semester. I asked what they knew about the project. "Not much," one student spoke with trepidation, "that it's hard," volunteered another. For others meaning is primarily found in the *opportunity to help someone*. A student who was particularly adept at consulting with the client at each step of the project explained to me that he really enjoys working with the client, that when the client came to their class the first time and spoke to them that this student was nearly moved to tears. The students demonstrate that the meaning of the project is some combination of these perspectives, along with meaning and emotion tied to group work and demanding schedules.

The professors shape the meaning of the project by redirecting students towards a *client-centered perspective*. The professors didn't dismiss the notions that this project was cool, or big, or scary, but they did, through the design of the curriculum and their

speech, demonstrate to students that the meaning of the project rests primarily in the opportunity to serve the client. This was made particularly visible by the professor who made their section of Design I redo the personas of the client because the students had failed to capture the essence of who the client is. It was also literally visible when the poster sized personas of the client were hung in the bike lab where the students spent most of their fabrication time. The professors used this project to teach principles of design to the students and the lessons were frequently related back to the specific needs of the client. However, for the professors with the most experience teaching Design I, relating course material to the client went well beyond application of new concepts to embedding the client deeply into the meaning of the project.

The curriculum lends itself to both sensegiving and learning through sense*making* in the early parts of the project, but frustration and a lack of mindful engagement seems to limit what students get out of the exposition portion of the project. Moore and Koning (2015) use the phrase "sense-enabling activity" to describe learning activities that are designed to trigger reflection and get learners to think about what they've done. Throughout the project, students were required to track their progress, explain their decisions, and reflect on the process. Sense-enabling activities were embedded into every lecture from practicing and reflecting on active listening prior to meeting the client to writing individual reflections when the project is complete.

However, the students demonstrated great variation when it came to their ability to recall what was learned, and thus applying the lessons to novel situations. As one senior student put it, "we're still not getting some of this stuff." One barrier professors face when trying to get these lessons to 'stick' is the because of expectancy violations felt

by the students, specifically manifested in the frustration some students feel about the structure of the project which violates the expectation that their work will be "hands on." Fabrication is only a part of design, but some students express that it should be a larger part. Frustration also manifested as message fatigue. Among some students, the lessons in design feel redundant because they are part of the curriculum every year in the program, even though some of these same students would struggle to tell you what those lessons are. Another barrier professors face is fighting for the students' attention, as the students juggle often conflicting priorities.

Students may ration attention away from the bike project in the exposition portion of the project in an effort to balance demands. Time and energy are finite resources and the bike project is one of many engineering classes the sophomore students must ration some of those resources for. As one student explained early in the second semester of the project, "Engineering Management and Statics and Dynamics are my most time consuming classes right now, but I expect that will shift later in the semester as this project takes up more time." The juggling of many demands is a common theme in conversation with undergraduate engineering students, as is reflected in their constructed 'personas' of a sophomore engineering student, described as a student who is stressed, tired, and balancing many things.

Divided attention as a result of juggling priorities may limit the students' ability or desire to engage mindfully. Guiette and Vandenbempt, (2016) explain detached coping as a deliberative form of sensemaking that makes use of performance indicators to make sense of actions in retrospect. Conversely, mindful coping is sensemaking that is both engaged in activity and deliberative. Mindful coping disrupts poor sensemaking by

surfacing taken for granted assumptions. The students' focus on points received for assignments (performance indicators) with the trouble some students have applying the processes learned, suggest that the sense-enabling activities manage to get students to reflect on their actions (detached coping), but not necessarily mindfully. Of course, some students are mindfully engaged from day one, can apply what they've learned very well, and carry those lessons forward onto other projects. This section explored the possible barriers for students who struggled with the project or expressed frustration, but experiences varied widely among sophomores. Mindfulness in sensemaking may help students recognize inconsistencies or inaccuracies in their sensemaking. As we'll see in the next section, disrupting sensemaking is important to successful completion of the project.

***Mediated Sensemaking*:**

> "[They] told me what my options were." – a student explaining how they found the solution to a design problem

> "The professors are trying to make us better, not break us down or fail us." – a student sharing their perspective on the sometimes uncharitable tone of feedback from professors

In the action portion of the project learning shifts from the professors sensegiving to the students sensemaking. The professors were still very involved in the sense that is made though demonstrating *mediated* sensemaking. Strike and Rerup (2015) observed mediated sensemaking as slowing action and facilitating doubt. The ethnographic interpretations suggest the value of expanding the definition of the phrase mediated

sensemaking to include any intentional disruption of sensemaking to produce better outcomes. For example, the proof of concept assignment and presentations are a particularly on target representations of what mediated sensemaking can be and do. Additionally, conversations with other experts in the department and the client produced better design outcomes by expanding input and options.

The proof of concept assignments and presentations are a paragon of mediated sensemaking. This series of three assignments is an opportunity for students to test some element of the design. These learning activities occur prior to the actual build phase, and if taken seriously can function to help students identify where they are having problems before they find themselves in a serious time crunch. As an assignment that puts students in the position to mindfully examine and reflect on very specific areas of their design, the proof of concept assignments are sense-enabling. Beyond that, these assignments bring the students into conversation with the professors about specific areas of their design.

Students who take the proof of concept assignments seriously demonstrate how they are making sense of the project. As novice bike builders, the sensemaking that occurs across group members may gain momentum in unhelpful directions. This is the crux of mediated sensemaking, that before the build phase starts, students can be redirected if they are heading down a path that isn't likely to lead to success. The conversations between students and their professor during proof of concept presentations may affirm the students' conclusions, redirect students towards better interpretations, or make sure the students understand the information they have gathered and are applying it correctly. For example, one type of proof of concept takes the form of meeting with the client to clarify what the dimensions of the human-powered vehicle. The students may

know that the client prefers to sit at an angle, but exactly what angle and how far away from the back rest do the handlebars need to be to make sure the clients' arms are comfortable when they are sitting at that angle? When a group of students presents a dimension-clarifying proof of concept, the conversation with the professor addresses whether the information obtained is being appropriately understood and applied.

The benefits of the conversations that emerge during proof of concept presentations vary with the quality of the proof of concept. As one professor explained, "a good proof of concept will give us lots to talk about." If a group of students presents something that doesn't qualify as a proof of concept (e.g. a mockup), they are not in a position to get valuable feedback. However, if a student comes in having attempted to build a customized part of their design, that is, a part that cannot be purchased off-the-shelf, whether what they built works or does not work, they are closer to the solution they need. The conversation with the professor in class may take the form of *troubleshooting*, *brainstorming*, or *redirecting*. The mediated sensemaking happening in these proof of concept presentations manifested as questions and comments that steer sensemaking.

Outside of the proof of concept assignment, teaching style could lean either towards sensegiving or mediated sensemaking in the exposition and action portion of the project. For example, one professor volunteered interpretations for how the information presented in class could be applied to the students' specific projects. Another professor also steered the students towards interpretations, but did so by asking questions and waiting for the students to 'sensemake' their way to an interpretation. If the interpretation was in line with the direction the professor was heading, the interpretation was affirmed. If it was not, then another question was asked. In the end, the interpretation that aligned

with the curriculum was promoted, but in one section it was done through sensegiving and in another section through mediated sensemaking. Mediated sensemaking took place outside of the classroom as students sought input from other experts in the department.

When facing a dilemma in fabrication, students sought out advice from experts, another way sense is mediated. Disruptions in fabrication sometimes manifested as a part that couldn't be obtained or a system that failed. When students were unsure what to do next, they sought out advice from people with greater expertise than themselves. By entering the conversation with students, experts participated in sensemaking and expanded the potential solutions the students could draw from. Sutcliffe and Weick (2008) explain a 'repertoire of responses' a group may use to cope with overload and continue progressing towards a goal. Early responses rely on the tools and knowledge already known and when those are exhausted, the focus shifts to containing the problem or changing the goal. Experts possess a much wider range of options (manifested as knowledge, tools, and skills) to draw from to mitigate or contain problems as they arise.

By pulling experts into the conversation, students expanded the available options for addressing problems as they arise. For example, the bike expert took one team's human-powered vehicle to his personal shop where he could use a fork widening device that wasn't available in any of the makerspaces on campus. Another team needed a machined part that they wouldn't have had time to obtain from the machine shop but again, the bike expert was able to draw from his own resources to keep the project progressing forward. There were many instances of students just being unsure and seeking out input from an available expert. In these instances, I observed the experts making sure the students knew what their options were, suggesting what might work the

best, but ultimately letting the students make their own decisions. Not all the teams made a habit of seeking out input. There were teams, like Team Herding Cats, that avoided engaging with the experts until near the end of the project.

Teams that did not include the available experts in their sensemaking throughout the project necessarily shifted the goal of the project. As Sutcliffe and Weick (2008) suggested would happen when other options for overcoming a problem are exhausted, having failed to adequately address or contain problems in fabrication, teams changed the definition of success. The original goal of the project was to design a human-powered vehicle *for the client,* but for teams with considerable problems in fabrication the goal shifted to a human-powered vehicle that was passably operational. At the final presentation, when the client tested all the human-powered vehicles, some of the vehicles were demonstrably not well suited for the client. While other teams' designed human-powered vehicles that were appropriate for the client, but in failing to regularly seek out the client's input, resulted in fabrication choices that made their bikes more difficult to ride.

Bringing experts and the client into the sensemaking process increases variety, which led to better outcomes. As Weick (2006) addresses, outcomes differ depending on who is participating in sensemaking; he notes there is value in variety. To this I can add, while including certain perspectives may be beneficial, there will be some perspectives that if not included do more than limit the potential benefits of that voice; instead, the absence of that perspective becomes detrimental to the team's mission. For example, one team had all the right systems on their human-powered vehicle, but those systems were positioned in a way that was difficult for the client to operate. There were many reasons

why a team may not have communicated with the client as often as would have been helpful. Some of these reasons related to conflicting schedules; often it was a simple lack of coordination on the part of the students during the chaotic build phase. Other times, students appeared to avoid interactions with the client precisely because they would need to modify their projects. Several teams appeared to fall into a trap of wanting to wait until later in the build process to meet with the client (perhaps when they would have something substantial to show), but the later a team waited, the harder it was to coordinate those meetings and more difficult it was to apply the information gleaned from the client to the bike. In the action phase, students were in charge of making sense of their work and outcomes varied with their ability to bring the right people into the sensemaking process. Sensemaking shifts again in the resolution portion of the project when the building is complete and it's time for the students to explain what has happened.

Sensemaking as Storytelling:

"I think we can talk our way out of it." – one student explaining to another that knowing what to say is more important than having known what to do

"I like the final presentations because we get to tell our story." –a junior student reflecting on the resolution of the bike project

In the resolution portion of the project, students 'make sense' of their experiences through reflection and the construction of narratives. The action portion of the project, the build phase, was a whirlwind of activity and the students face ambiguity they must reckon with when they create a report explaining what happened. As Weick (1979, 1995) points out, ambiguity triggers sensemaking. This sensemaking manifested as storytelling

in the students' final reports and presentations. Sensemaking as storytelling functioned to justify decisions, add meaning to the project, and was part of establishing an engineering identity.

Sensemaking as justification emerged when students gave an account for decisions that were made on the fly – that were improvisations. For many of the teams, the work done in the action portion of the project could be described as imprecise and improvised. The human-powered vehicles were under design at every step of the project. That doesn't mean it was bad work or that projects unfolded any differently than was intended or expected by the professors. It does mean that the explanations were constructed rather than recorded. By the time these constructed narratives were shared with the client, professors, and others, the haphazard processes of completing the human-powered vehicles was obscured by cohesive stories reflecting the design process that was taught in class. As Weick (1995) points out, sensemaking favors plausibility over accuracy.

The meaning of the bike project was co-constructed in the resolution portion of the project as students' shared their stories with the client and the client responded. The storytelling in the students' final presentations highlighted how the design decisions students made along the way were done for the client with the clients' needs in mind. As the client tested the human-powered vehicles and expressed their sincere appreciation for the students' hard work, the students were able to place the chaotic events of the last two months into the context of the clients' story. In so doing, meaning was added to the students' efforts, meaning that helped shape the students' engineering identity and position in the program.

Sensemaking as storytelling in the resolution portion of the project facilitated the construction of an engineering identity within an emergent community. Identity and positionality are constructed in the narratives of past events (Vaara, 2002). As meaning was established in the project, so were the students' identities relating to their work on the project. The students were not simply engineering students, but students and managers, students and makers, students and designers, and so on and so forth. Taylor (2009) says about stories and work, "stories are ways by which closure is established: how a resolution was brought to a problem, but also who was a friend or ally and who was not" (p. 171). It was appropriate that constructing a narrative to share at final presentations coincides with peer evaluations. This reflection on who was an ally when the bicycle parts were scattered everywhere shaped the community among juniors. Juniors demonstrated a strong sense of comradery following their shared struggle in the bike project along with greater investment in the department as full members of the program.

The way community was experienced by juniors appeared related to the events of the bike project. For example, Olivia was on a team that struggled a lot, but she arose as a hero on that team for her prowess as a welder. That prestige followed her into the junior year. Students who weren't engaged at all, weren't invited to be a part of the community the following year. A few students completed the bike project but in a way that felt unsatisfactory. There were students who made it across the finish line, like Sara, but they were dragging a pile of metaphorical broken parts behind them. These students were still a part of the junior community, but with observable self-doubt in their engineering identity. Besides human-powered vehicles, outcomes of the bike project include

professionalism and community. Sensemaking, in all its variations, was integral to experiences of students in the bike project. In the next section I will explore another aspect of the bike project that greatly impacted the experiences of the students: their teams.

Units of Coorientation

A student's group, their unit of coorientation, impacts the sensemaking, and therefore learning that takes place. Taylor (2009) explains that the state of the object and the state of the members in a unit of coorientation are emergent and dependent on one another. Applied here, this means that the state of the human-powered vehicle depended on the state of the team members and that the state of the team members depended on the state of the human-powered vehicle and each other. That is what it means to be in a unit of coorientation. In this section we'll explore the characteristics that differentiated the teams and the impact that had on outcomes. Observable differences in teams included level of engagement, level of expertise, rigidity of roles, and sensemaking.

The greatest factor differentiating one team from another was level of engagement from the participants, followed by expertise of members. As the data were analyzed and interpreted, three archetypes of teams emerged. These archetypes were named for the sake of the narrative presented in this thesis, so I will use those names as I elaborate the attributes of each team type. There were nine teams of around nine students designing a human-powered vehicle for the client. Three of those teams can be described as *Team Engaged*, three as *Team Up & Down*, and three as *Team Herding Cats*. (The name Herding Cats comes from a conversation with the project member of one of those teams who described working with her team as trying to corral cats). The first distinction

between these teams is the number of students on the team who are engaged and working. On both Team Engaged and Team Up & Down, most students on the team were actively involved in the completion of requirements. This dropped significantly for Team Herding Cats, one team got through the project with only half of the students regularly interacting with the project. After level of engagement, level of expertise distinguished one group from another. Team Engaged had one or more students whose expertise was significantly more developed than the other team members. On Team Up & Down student's expertise was more closely aligned and could be described as Advanced Beginner moving into Competent (Benner et al. 1996). There were students on Team Herding Cats that demonstrated more expertise than their teammates but that didn't improve outcomes because expertise was insufficient to compensate for lack of engagement. On teams with student experts, decision making was more centralized and roles more rigid.

Differences in sensemaking were observable in communication and decision making depending on the rigidity of roles. "Sensemaking is a diagnostic process directed at constructing plausible interpretations of ambiguous cues that are sufficient to sustain action" (Weick, 2005, p. 55). Sensemaking in the build phase was figuring out what was happening so you can figure out what to do next. It was not necessary for all members of the team to participate in that process. On Team Engaged, students ended up in distinct roles due in large part to the concentration of decision making among a few members with more developed expertise. On these teams, it was fine for one person to write all the memos or do all of the communication because their help wasn't needed in the problem solving related to fabrication. On Team Up & Down, decision making and problem solving was decentralized. Team members were less likely to occupy one role as the team

worked together to problem solve issues in fabrication. On Team Herding Cats, too few people were doing all the work so communication and decision making appeared erratic and while one person may end up doing all of one job it wasn't because someone else was doing all of a different job.

Outcomes were connected to team type. As mentioned in the previous section, Team Herding Cats was less likely than other teams to seek out important expert input early in the process. An interesting outcome related to this was the complexity of their designs. These teams were more likely to have overly complex designs that were difficult to fabricate, perhaps because they missed opportunities to be redirected in the way they were making sense of the project. Experience demonstrated that the teams could only go so long avoiding expert input, particularly since every human-powered vehicle needs to pass a safety check before the final presentation. Team Herding Cats didn't spend much time with the expert early on, but dominated the experts' time right at the end of the project. The experts found creative ways to get Team Herding Cat's human-powered vehicle across the metaphorical finish line of the safety check and final presentation.

Aside from human-powered vehicles, outcomes of the bike project included skills development in students. Team Engaged got through their bike project together and mostly unscathed, but the skills that were developed were segregated by their distinct roles. For example, students in the role of fabricator developed confidence and expertise in the engineering makerspaces. This expertise development was facilitated by the interactions with others in the spaces who possessed similar or more developed expertise and facilitate apprenticeship (Lave & Wenger, 1991). On teams where all the fabrication was done by a few students, those students got the most benefit from learning in

makerspaces and showed the most growth in that area. On teams where fabrication was a shared responsibility across the team, more of the students got some skills development, but not as much as the 'designated' fabricators on other teams. Rigid roles ended up being better for getting through the project but not necessarily for learning.

Table 1 Team Archetypes

Team Archetype	Engagement	Expertise	Rigidity of Roles	Outcomes
Engaged (Team Engaged)	High	Advanced expertise held by subset of group	Rigid roles and decision making centralized	Skill development was segregated depending on students roles and tasks on the team.
Variable (Team Up and Down)	High	Similar levels among group members	Flexible roles and de-centralized decision making	Skills were developed more evenly among group members.
Fractious (Team Herding Cats)	Low and moderate	Advanced expertise held by subset of group	Labor left to few engaged members and decision-making erratic	Failed to seek client and expert feedback, resulting in overly complex designs.

There was an arc of tension that teams experienced in the project, illustrated in the narrative of this thesis, but shaped differently depending on team type and how seriously students took assignments in the exposition portion of the project. However, it isn't clear if early engagement led to better outcomes or was simply a demonstration of which students were going to be more engaged in the project later. There were teams that had a very impressive looking proof of concept but who floundered in the build phase; so it isn't clear the relationship between early work and project outcomes. It would be worth exploring proof of concept assignments to evaluate which 'tests' result in valuable information that eases the tension in the build phase and leads to better outcomes. Still,

teams that had more engaged members and took early assignments in the project seriously, had an arc of tensions that rose earlier but never gets as high as the teams that put off figuring out their projects. Teams that didn't know exactly what they needed for their bill of materials, or who still didn't have most of the dimensions figured out before the build phase experienced a sharp rise in tension in the action portion of the project. There was a certain amount of work that was going to be done, there was a certain amount of tension that was going to be experienced, some teams did better than others spreading that work and tension out across the team members and the time allotted for the bike project.

Membership Negotiation in the Organization

"That's not engineering, that's imagineering." – a criticism of the design curriculum which strays from a traditional approach to engineering education

Students negotiate their membership in the program by fulfilling the program requirements and responding to the values of the department. The fulfillment of requirements is discussed at length above along with developing professionalism and community, demonstrating how the answers to the two research questions, though discussed separately, are inexorably intertwined. This section is dedicated to the student interactions with the organization, and thus explores how students build communities of practice as they respond to the department's values and promoted definition of the profession. As described in Chapter 2, organizational values are communicated to the students via the curriculum, spaces, and formal and informal communications with faculty, staff, and other students. Members of the organization may align or contrast with the dominant values. As students navigate the program, they build relationships with

others whose values (and definitions) reflect their own. By joining the program, the students have made a choice to become 'engineers,' thus embarking on a journey to define engineer and self.

Students may accept, reject, or compromise with organizational values and in so doing define what it means to be an engineer. In the section on sensegiving, I addressed how professors communicate the meaning of the bike project. The professors also communicate what it means to be an engineer. This communication emerges as part of the curriculum and in improvised communication. Design I begins by exploring what it means to be an engineer. The student responses to the question "what do you think it means to be an engineer?" reveal that their concepts of "engineer" may relate to analytics, fabrication, design, curiosity, innovation, and more. It is understood by all in the room that different students will be exploring different paths with their general engineering degree. In this course they are presented with what engineering as design looks like, and it is strongly inferred that these are skills that the students will need no matter what path in engineering they choose. The students' skills may vary along with what roles they perform on their teams, but design is universally applicable. The professors are presenting, not just a collection of skills, but a perspective that each student should become familiar with as an engineer. As a large project within a project-oriented program, this perspective aligns with the overall communication of organizational values.

Communications with students about what it means to be an engineer also occur as extemporaneous speech inside and outside of class. For example, "in my line of work, if you get it wrong, people die," or, "at the end of the day, it's your name on the line."

These are two examples of the kind of speech that might get tagged on to a lesson, in this case a lesson about ethics in engineering. Students pick up and repeat the utterances that align with their own developing understanding of engineering. For example, one student, wanting to express the difficultly she was having with too many demands from professors said, "They want to see how much I can take before I break and then they'll back off a little." This was the same language used by a professor describing what we can learn from failure. Another student, sharing a criticism of the program, stated that only three professors in the department were conducting research. They said this even though most, if not all, the professors in the department are conducting research because this student only recognizes a narrow type of research as 'real' engineering research, e.g. research on concrete. This student's statement was parroted, verbatim, from a complaint from someone else working in the department. This demonstrated that the students are negotiating with organizational values, starting with their own perceptions of what it means to be an engineer.

The students come into the program with values, expectations, and beliefs of their own and it is with these values and expectations the organization must negotiate. For example, Sara expressed that she needed to be good at fabrication to achieve what being an engineer means to her. Doyle expressed frustration with the curriculum used in Design I and II because it didn't fit his expectation of what engineering education should look like. Cody was critical too that his contributions to fabrication didn't compensate for his laxness in the written assignments. Michael embraced engineering as both design and fabrication communicating to me that fabrication skills make him better at design. He can navigate multiple spaces and communities in the department, what Taylor (2009) would

refer to as a bridge. Another student expressed that this program aligned exactly with their concept of what engineering should be. This student struggled with math and had to retake some of their math courses, but leaned into the opportunity to ideate and create and has been successful in the program. Students may reject, accept, or compromise with the interpretations presented by the professors.

Sensegiving, is sense given, whether it is well-received or not. Rejected sense, as in the rejection of how engineering is defined by the department, creates haunted definitions (Putnam, 2019). One alumnus who rejected a program promoted definition of engineer while at State U relayed to me how he later came to embrace it. It wasn't until he obtained his first job outside of the program that he realized his own closely held definition of engineering made for miserable work. He found a different job and joy in his work by adopting the definition that he had previously rejected. That is not to say that one definition is right and the other wrong, but instead to demonstrate how, when the held definition failed to produce a desirable outcome, the other interpretation was readily available to draw upon.

As students affirm or reject organizational values, they build relationships with others who share their way of 'making sense," this leads to the development of communities of practice within the organization. Taylor (2009) states that communities of practice develop their own rationalities and language, making them cognitive domains. He suggests that rationality and shared language are the result of working together, but this research aligns with Wenger's (1998) explanation of CoP's in organizations that describe them as self-organizing. That is, it was the shared language and rationality that brought these community members together into a CoP, not their presence in the CoP that

led to the development of shared language. Having said that, by affirming the values of other CoP members, these values were strengthened, and the language cemented and expanded. This much was evidenced by the use of similar phrases to critique the program among members of the same CoP.

Language, specifically definitions of a small set of words, made visible the differences in rationalities from one CoP to the next. The words with connotations that differentiated ways of making sense were engineer, project manager, research, and design. There are probably others, but these were the areas of equivocality that were presented in the course of this ethnography. A small group of students I spoke to use the phrase "project manager" to mean someone who is not an engineer but at best engineer adjacent. Used this way, project managers aren't 'real' engineers. A criticism among students who used the words project manager this way was that the program, which promotes developing managerial skills, isn't preparing students to be engineers. One student of this mindset, a senior, described how he differentiates himself from the community of project-managers-to-be by 1) seeking out mentors holding similar perspectives, and 2) creating his own experience within the program. This student explained that opportunities exist within the program but not many people are taking advantage of them, which is good for him because it gives him more space to do what he wants. Implicit here is an idea that the program can produce some engineers, but only if the student carves out a path with the help of the faculty and staff who know what it takes to be a real engineer. In a similar manner, 'real' engineering research is research on tangible materials, not ideas. 'Real' design is described as rapid prototyping. These are

the definitions that counter the department promoted definitions of engineering as entrepreneurial innovation and design as a process that starts well before fabrication.

The CoP that counters department values with a narrow definition of engineering congregates around the fabrication spaces. Not everyone in those spaces is a member of that CoP. Indeed, there is an entirely different but smaller CoP that congregates in those spaces too. However, in general, the fabrication spaces are the physical spaces where traditional ideas of engineering can find a home. This creates a split culture between the upstairs and downstairs in the engineering department, because most of the fabrication spaces are downstairs. As I spent time in these spaces the differences became apparent, but eventually, so did the similarities. I will end these interpretations with the ideas that transcends the friction between definitions of engineering.

Despite differences in how members of the organization define engineering, they are joined under an umbrella of dedication to education and a belief that anyone in those spaces "can." As one professor from upstairs stated, "you have to go into it believing that anyone [in class] can do it." A staff member downstairs stated, "anyone can, but it takes work." The students self-sort into communities with these mentors and leaders, seemingly following their own beliefs in what engineering is or should be. However, no matter where they land in the program, they will have access to educators who believe that they are capable of being the engineer they see themselves as. Thus, apprenticeship played an important role in students legitimate peripheral participation in the CoP. Some of the people the sophomores look up to are faculty, some are staff, some are students further along in the program who may work as apprentices or teaching assistants, but all are teachers when they take advantage of the opportunity to help students learn, an

important part of legitimate peripheral participation as students move from the outside to the inside of a CoP (Lave & Wenger, 1991). In this manner, the engineering department is its own sort of CoP, and the pattern of behavior (Taylor, 2009) that constitutes this community, is the eagerness I observed every day I was in those spaces to share some bit of expertise with an interested learner.

Theoretical Implications

Departments in higher education are more than a collection of independent classrooms, they are an organization. The values of an organization, and the definitions that emerge relating to the values, will always be under negotiation. Much of the scholarship on membership negotiation focuses on workplaces in which employers aim to shape and retain workers, and employees aim to find suitable roles for themselves within the organization (Bauer, Morrison, & Callister, 1998). This stands in contrast to the university and academic departments as organizations in which students must negotiate membership but are also then sent outside of the organization to fill roles in other places. When learning is the primary goal of an organization and one of the populations is transient, membership negotiation takes on different functions that were yet to be thoroughly explored in existing research. This ethnography presented a unique and promising opportunity to address this gap.

This ethnography shows us that students' membership negotiation in the form of responding to organizational values impacts their learning experience. Further this ethnography clarifies the difference between a community of practice and a unit of coorientation. Wenger (1998) and Taylor (2009) present competing ideas of how CoP develop. Further, Taylor (2009) introduces units of coorientation as the foundation of

CoP. This research clarifies these two descriptions of people working together. A clear example of units of coorientation were the designated teams of Sophomore students. The object was the human-powered vehicle and the team members were oriented to it and towards each other. As Taylor (2009) describes, the state of the object and of the members was emergent and interdependent.

These units of coorientation were temporary and possessed varying degrees of the coordination necessary for a cognitive domain to develop. On the other hand, communities of practice were observed having formed around opportunities for students in the program, such as the engineering outreach program and makerspaces. A group of students who formed a study group is another good example of a CoP within the organization. Within these communities of practice there is evidence of cognitive domains in the form of shared definitions.

This ethnography suggests that communities of practice emerge from the self-sorting of members into cognitive domains that fit their way of making sense of the world. This is in line with early assertions by Wenger that, even in organizations, CoP's are self-organizing systems (1998). As Wenger explains, "A community of practice is different from a team in that the shared learning and interest of its members are what keep in together. It is defined by knowledge rather than by a task and exists because participation has value to its members" (p. 4). This was demonstrated by the gravitating of students with a narrow definition rooted in traditional engineering education towards mentors who share that perspective.

Finally, this research demonstrates the values of ethnographic methodology. I have identified several implications of this research that emerge when viewed through the

theoretical perspectives of sensemaking and membership negotiation. Because this ethnography is presented as a story constructed from the students' experiences, as expressed by the students to me the researcher, it remains available to be reinterpreted from other scholarly perspectives.

I expected that I would use narrative as a device to communicate thematic observations about learning. I did not expect to communicate mostly in narrative or to follow the chronological events of the bike project. It wasn't until I went through my large pile of observations bit by bit that I realized I was responding to my own notes the way one might respond to a good book. I read again about the bent gear and I laughed. I read again about the final hours leading up to the alpha presentation and my pulse quickened in anticipation. Somewhere between feeling annoyed on Sara's behalf when Doyle interrupted her and the great wave of relief and joy when the client came wheeling down the hall with Cody jogging behind, I realized the value of this research lies in the story of the students' experiences. Now that this narrative exists, it is available for further secondary analysis. There are many ways to make sense of bent gears and real engineers, I have presented one of those ways to you here.

Limitations

Being an outsider in the engineering department was both a limitation and a benefit. It was a limitation because there may be important observations that were missed simply because I lack familiarity with the work students had to do and the culture surrounding engineering as a discipline. It was also a benefit because I added variation to the sense that could be made of what is happening in the department. With a background

in sociology and communication, I went into the spaces attuned to issues of identity and culture. This led to different outcomes than the other researchers on the team.

Another limitation relates to restricted access to the community I was observing. As a non-traditional student with a family, I could not be on campus to observe the students in the evenings or on the weekends. Furthermore, student life happens in pockets that are inaccessible to people who are not also undergraduate students in the 18-22-year range. This meant I had to draw from student reports to fill in the missing pieces. This aspect of my research evolved from a limitation to an important feature as student interpretations of their experiences became a focal point of this ethnography.

Finally, like the bike project, this ethnography had moments of brokenness and mess. At the final presentation, the students brought out their human-powered vehicles but left the broken pieces on the floor of the bike lab. Likewise, there are pieces of this ethnography related to power relations and social location that remain unaddressed. The work of understanding learning in makerspaces and membership negotiation among students would benefit from a an intersectional/critical lens that surfaces the experiences of students who are marginalized.

Future Research

The phrase 'mediated sensemaking' was offered by Strike and Rerup (2015) to explain a role of third parties in the sensemaking process. The term sensegiving was coined by Gioa and Chittipeddi (1991) to explain how incoming leadership in an organization may promote their agenda of change. Both emerge from management studies. Sensegiving has been cited sporadically in strategic management and organization research. Mediated sensemaking has been introduced but not expanded on

since. Within this applied research of sensemaking in learning, sensegiving and mediated sensemaking play important roles as educators steer students' sensemaking. This is an area that is ripe for further exploration and development.

Further, the examination of an academic department as an organization proved vital for understanding the movement of students into communities of practice as they interact with organizational values and navigate competing definitions. This research provides an adaptable framework for evaluating departmental values, exploring how those values are being communicated, and identifying the development of communities around language and rationality. What this research does not do, is offer a suggestion for what to do with that information. That is work I leave for educators and future researchers to pick up and carry forward.

Final Reflections

Working through the stories of the sophomore students on the bike project revealed a number of commonalities between building a bike and constructing a thesis; it would seem that big projects of many varieties may have some qualities in common. Through the lens of students' experiences, I learned things about my own work. For example, as I noted the complexity of design for students who avoided bringing needed perspectives into their sensemaking, I was forced to consider my own struggle to find the boundaries of this project and who I was or was not receiving feedback from. As I described how the students' projects emerged from the mess of the bike lab and the tensions in the building phase, I reflected on my own mess of papers and notes and the tensions through which this thesis was birthed.

Going into this research with a naive understanding of what design is, I thought the process was thinking up what you want to make and then making it. Through the experiences of the students on the bike project, my own experiences with this thesis, and the ever-evolving bike project itself, I realize there is not a line where the design part stops and the construction part begins. As long as the project is in your hands, it is still under design, but isn't that a true reflection of what it means for something to be constructed? Some of the sophomore students were carrying that same flawed expectation, as evidenced in the phrase "less thinking, more doing" to describe the transition from exposition to action. A more accurate description would be, "thinking, doing, more thinking, more doing."

Finally, my experiences and the experiences of the sophomores have demonstrated that nothing works out just the way you expect it to. The sophomores had the experience of "fix one thing, and another thing breaks." I too found myself thinking over and over again that I had a handle on the thesis writing process and knew how it would come together, only to face my own 'broken pieces' in the form of ideas that didn't come together well or one of life's many interruptions that delayed the work being done. For all of us, the unexpected disruption of a global pandemic was a very dramatic example of this. For me, this meant finishing my thesis at home, away from the engineering department and the students whose stories I had become invested in. Things don't go as planned, you can be okay with that, or not okay with that, but there's not a lot you can do to change that.

Spring 2020

It's the last day before spring break and the engineering students are eager to finish mid-terms and get out of here for a much-needed break, many of them have already

left. I'm sitting in the research lab, typing away as I turn so many observations into what I hope will be a good story. I have struggled to wrap myself around this thesis, but the department will be empty next week giving me plenty of quiet time to catch up. I'm sure I'll get caught up then. Like the sophomore's bikes, my thesis has gone through a series of changes as I find my way to something that works.

My typing is interrupted by a knock on the glass. Looking up, I see Olivia waving on the other side of the door. I half stand while we both pause momentarily. She is waiting to see if I'm coming to the door or if she should move on. I'm waiting to see if she is waiting for me to come over or if I should sit back down. Seeing her hesitate I shuffle across the floor in my socked feet to open the door and chat with her. Olivia laughs at my polka-dotted socks noting that I've clearly made myself at home.

"That makes sense though since this is your room now."

"Yes, next semester is going to be strange."

"What happens next semester??"

"Well, I'm graduating, I'll be gone."

"What? No, that's not fair. You have to stay until I graduate!"

"It isn't fair," I joke, "but don't worry, I'll visit, and I'll come back for FabCon next year to see everybody's projects."

"You better."

"I definitely will," I assure Olivia, and wrapping up our conversation I tell her, "have a great break!"

"You too," she replies, "I'll see you in 10 days!"

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