Beyond the Classroom: Understanding the Educational Significance of Non-Curricular Engineering Design Experiences

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ABSTRACT

The purpose of my dissertation study is to better understand the educational experiences of undergraduate engineering students within non-curricular learning environments, specifically in the form of extracurricular engineering groups or programs. I first conducted a content analysis of engineering education literature to identify where engineering design learning occurs, and to synthesize the implications of studies regarding engineering design learning. Aiming to fill a gap in the literature regarding non-curricular learning contexts, this study investigated what extracurricular groups and programs can educationally provide undergraduate engineering students by observing and interviewing students engaging in these environments. This study also aimed to identify if and how engineering students find navigational flexibility within engineering curricula, and how non-curricular learning environments might provide navigational flexibility.

With regard to where engineering design learning occurs, the literature points to various educational contexts that effectively deliver engineering design education. Strategies that involve authentic and longer-term engineering design experiences tend to be the most impactful in terms of student outcomes and perceptions, however those experiences are not always implementable at larger scale. More traditional educational approaches to engineering design learning, though less impactful, are still effective delivery methods for introducing key aspects of engineering design education (e.g. modeling, global/societal/economic/environmental factors, communication skills). However, there was limited literature regarding more non-curricular learning experiences, such as learning in designed settings, outreach learning, learning media, and everyday informal learning. This literature review is one of the first attempts towards synthesizing where and how engineering design learning occurs, and has identified a significant gap in the literature regarding non-curricular educational settings.

Addressing the identified gap in engineering education literature regarding non-curricular learning experiences, this dissertation study investigated five non-curricular engineering learning sites for undergraduate engineering students at a large research-driven state institution. Informed by the preliminary findings of a pilot study, I first investigated the salient features of engineering-related non-curricular activities from the students' perspectives using a self-directed learner autonomy framework to guide the study. Students participating in extracurricular engineering environments exhibited strong attributes of self-directed learners, particularly a willingness and ability to be challenged and to learn. The educational environments of the extracurricular opportunities cultivated these self-directed learning attributes by providing

students a space to be exposed to an engineering community, authentic engineering work, and accessible resources. Findings from this portion of the dissertation indicated necessary modifications to the self-directed learner autonomy framework used to guide this study. The modified framework contributes a possible approach towards future assessment or research pursuits regarding non-curricular learning experiences in engineering.

I also investigated the role non-curricular activities play in providing engineering students navigational flexibility through engineering curricula. Extracurricular engineering environments afford navigational flexibility by offering students opportunities to work on motivating challenges with and among supportive communities. By providing a space for students to express their engineering selves in primarily self-directed ways, extracurricular engineering experiences cultivate students' drive to find and pursue personally meaningful curricular and non-curricular educational experiences. However, institutional barriers, particularly time constraints and institutionally recognized achievements, stifle students' flexibility and willingness to pursue personally meaningful experiences. The findings of this study have helped uncover the various affordances non-curricular learning experiences provide engineering students, but more importantly, have identified the institutional barriers that prevent students from taking full advantage of non-curricular learning experiences. Based on these findings, I recommend that university and program level structures be reevaluated to encourage and provide students with more flexibility to find personalized learning experiences in and out of the classroom.

Dedication

To Kris

My partner for this insanely challenging project called life.

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CHAPTER 1: INTRODUCTION & MOTIVATION

1.1 Introduction

As identified by the Learning in Informal and Formal Environments (Stevens et al., 2010) Center, approximately 90% of human learning experiences during the undergraduate years occur in informal learning environments. In order to comprehensively understand the educational experiences of engineering students, it is critical to consider informal experiences in addition to formal experiences. Furthermore, formal environments in engineering education typically involve many different educational activities, so it is important to identify what constitutes as "formal" undergraduate education. A better understanding of the multitude of ways in which students learning engineering is useful, not only from a theoretical perspective but can also help guide curriculum and mentoring efforts. For instance, it is well documented that student persistence and retention is a critical concern across STEM disciplines and engineering has been especially troubled by both migration of students out of engineering and an inability to attract students into engineering (Ohland et al., 2008). Most suggested solutions to this issue have been institutional – as suggested by the pipeline metaphor – but recent studies take a more multidimensional view (Stevens, et al. 2008) emphasizing the standpoint of students. Students are now seen as more directly engaged in the design of their "pathways" or personalized learning trajectories and leverage "navigational flexibility" available to them (Baxter-Magolda, 2001, 2004; Stevens et al., 2008) often follow "unofficial routes". Investigating these "unofficial routes" engineering students might take is vital in order to expand the understanding of the various contexts of engineering students' learning experiences (Stevens et al, 2008) and to holistically account for situated engineering learning (Johri & Olds, 2011).

In spite of the evidence for taking a broad view of personal trajectories of engineering students, engineering learning measures are still largely focused on assessing formal instructional outcomes. Traditional engineering teaching practices are designed primarily for providing "accountable disciplinary knowledge" or ADK to students (Stevens, et al. 2008) although being an engineer requires more than just mastering disciplinary knowledge. This chapter provides an introduction to the need, significance, and stakeholders of the proposed research study on undergraduate engineering students experiences in extracurricular engineering environments. I will briefly introduce the research questions and design, as well as discuss the limitations and bias. A few important definitions will first be presented in the following section in order to provide context and a common understanding.

1.2 Key Terms

The following definitions of key terms are presented in order to fully understand the context and assumptions from which I am working.

- **Non-curricular learning,** or out-of-classroom learning**,** is a term for educational activities that occur outside of obligatory curricular requirements. This term specifically refers to any activity with educational intentions that is not an explicit requirement for completing an engineering degree. Being the most aligned with the focus and scope of this dissertation, **non-curricular** activities will be the primary term I use to describe my research settings.
    - **Co-curricular activities** are possible learning sites where engineering students might be participating in non-curricular learning. The term **co-curricular** is particularly pertinent in situations where a student organization is a part of

students' academic and professional development (Andrews, 2013); where the organization explicitly facilitates or corresponds adjacently to a student's curricular requirements. A generalizable example of a co-curricular organization would be mentorship programs for underrepresented engineering students.

    - **Extra-curricular activities** are also possible learning sites where engineering students might be participating in non-curricular learning. In contrast to co-curricular learning, extracurricular learning is particularly pertinent to situations where students are participating in student organizations whose missions do not explicitly include facilitating or corresponding adjacently with a student's curricular requirements. A generalizable example of an extracurricular organization would be a Engineers Without Borders. Being most representative of the research context of this study, the term 'extracurricular', along with 'non-curricular', will be one of the primary terms use to describe my research settings.

- **Formal learning** refers to traditional learning environments, such as a well-structured classroom setting, where course objectives are pre-defined and standardized, and assessments are structured to determine if these standardized objectives have been met.
- **Informal learning** refers to unstructured educational experiences that might not have explicitly defined learning objectives or assessment protocols. Informal learning environments are described in the literature as "person-centered" and goal oriented environments (Bransford et al., 2005). Tradition, emotions, and personal identity have also been identified as significant factors of informal learning environments (Scribner & Cole, 1973).

- **Situated engineering learning** refers to the contextualization of engineering students' learning during students' undergraduate experiences, which can be formal or informal. (Johri & Olds, 2011)

- **Self-directed learner autonomy** is a combination of two existing theories:

    - **Self-directed learning** is broad theory, with many domains relevant to adult education research (Candy, 1991; Baxter-Magolda, 2004; Gureckis & Markant, 2012). For example Candy (1991, p.23) identifies four separate phenomena that self-directed learning refers to: personal autonomy, self-management, learner-control, and autodidaxy. Specifically for this study, self-directed learning from the autodidaxy domain, i.e. "intentional self-education", has implications towards students pursuing co-curricular activities (Candy, 1991, p.158).

    - **Learner autonomy** describes characteristics of students who are capable of learner independence. This theory has two primary components: a "willingness and ability" to learn, where willingness derives from a learner's "motivation and confidence", and ability derives from a learner's "knowledge and skills" (Littlewood, 1996, p. 428)

    - Self-directed learner autonomy, merges these two theories together, identifying a student's initial identification and desire for autodidaxy, and while also identifying a student's demonstration of learner autonomy.

- **Navigational flexibility** is a term coined by Stevens et al. (2008) that refers to **personalized learning trajectories** designed by students seeking non-traditional and customizable learning experiences.

1.3 STATEMENT OF THE PROBLEM & MOTIVATION

Engineering programs in the U.S. have worked towards improving engineering education to better meet the demands of the modern engineering student and the engineering professional. A recent approach toward improving engineering education has been to move emphasis away from theory-driven standardized education, characterized by traditional lecture-based pedagogies, and toward more design experiences, characterized by collaborative, creative, active, and informal learning approaches. Of the different non-obligatory learning experiences in which engineering students engage, design experiences are one of the most sought after. This is not surprising given the centrality of 'design thinking' to engineering practice and because of the opportunity for hands-on learning experiences. A common characteristic of successful design experiences described in the literature is that they are primarily nontraditional academic settings (i.e. studios, informal, service learning) and are offered to all undergraduate students, not just upperclassmen. Less successful examples described in the literature are typically set in traditional classroom settings, and are usually offered to only junior and senior level students who were more likely to have already established traditional learning habits.

The insight provided by engineering education literature is that non-curricular design experiences, and other non-curricular learning activities, should strive to enhance existing curricular opportunities, filling in academic gaps that traditional curricular activities do not have the time or resources to address. This is particularly pertinent in Research 1 universities, where undergraduate curricular experiences might be limited with large class sizes and limited resources, but where copious non-curricular design and research experiences are available to students. It is known that many students engage in non-curricular learning experiences, and that these experiences have a significantly positive influence on students' educational and professional development. However, there is limited understanding regarding the influencing features and barriers of non-curricular learning experiences, particularly within the context of engineering education. Closely investigating non-curricular experiences can help uncover a more holistic view of the student experience as a whole, providing a more situational understanding of engineering students' educational experiences.

1.4 Purpose of the Study

The purpose of this dissertation study is to better understand the holistic educational experiences of undergraduate engineering students, more specifically identifying where engineering design learning is occurring and how participation in non-curricular engineering-related activities influence students' educational experiences. There are three aims of this study, which will each be addressed and presented in three separate manuscripts contained in this dissertation (Chapters 3, 4, 5). The first aim (Manuscript 1, Chapter 3) was to identify where engineering design learning occurs. For this aim, I reviewed the extensive available literature regarding the various and unique engineering design education environments (at large research-focused institutions in the U.S.) that engage undergraduate students to learn engineering design skills and content. There are decades of reports and literature presenting unique engineering design learning experiences, however little has been done to comprehensively synthesize undergraduate engineering learning sites.

The second aim (Manuscript 2, Chapter 4) of this study was to explore students' experiences as they participate in non-curricular learning environments, specifically from a self-directed learner autonomy framework. Findings from a related pilot study that investigated the experience of students engaged in an automotive design team found that student autonomy, referred to as 'ownership' by the students, was a highly salient characteristic of students' perceptions of their experience with the automotive design team. Therefore, I further investigated students' experiences with non-curricular engineering design activities from a self-directed learner autonomy framework. Many engineering students participate in a variety of non-curricular engineering design activities, which have been shown to have significantly positive effects on student success (i.e. academic success, student retention, etc.). However, there is limited work considering *why* non-curricular activities are so beneficial to students. I believe the sense of agency that non-curricular activities provide students is an important explanation for the significantly positive impact of non-curricular activities.

The third aim (Manuscript 3, Chapter 5) of this study is to explore the ways undergraduate engineering students find navigational flexibility, or personalized learning trajectories, in engineering curricula. This involved investigating why students join certain non-curricular groups or programs, the intended goals of those engaging in non-curricular groups or programs, and the academic and professional development of these participants. First presented by Stevens et al. (2008) as one of the three main dimensions essential to students 'becoming an engineer', one beneficial opportunity that non-curricular groups or programs offer students is navigational flexibility. I investigated if and how engineering students seek navigational flexibility within engineering curricula, as well as the role non-curricular learning environments play in allowing undergraduate engineering students to find navigational flexibility. Personalized education is a topic with growing interest in the engineering education community, and I believe that engaging in non-curricular activities is one approach students take to find this personalization.

1.5 Significance of Research

This research provides significant contributions to engineering education practice and research. By investigating the non-curricular learning experiences of engineering students, I identified some of the the most educationally beneficial features of non-curricular experiences in order to better inform students, faculty, and future employers of learning opportunities outside of the classroom. The results of this study provided engineering programs with a more clear understanding of the educational influences and barriers of non-curricular activities. This information has already been used to help inform recruitment, assessment, and retention efforts of the organizations included in this study, and could continue to be used for similar efforts. It could also be used to help inform engineering faculty in terms of identifying important learning outcomes that students are achieving outside of the classroom, thus reducing the pressures regarding learning outcomes inside of the classroom. Recommendations stemming from this study are further discussed in the Chapters 4, 5, and 6.

Also, this study will provide significant contributions to engineering education research, particularly in terms of building upon existing literature on non-curricular engineering learning sites. Investigating extracurricular engineering learning is already a contribution to a relatively small body of existing literature. Much of the limited existing engineering education literature regarding non-curricular activities and informal learning environments tend to be quantitative studies that have identified that such experiences have significantly positive effects on students' educational and professional development. However, there is still much to be understood in terms of *why* and for *which reasons* these positive effects are being observed. This study has provided a qualitative approach that informs both engineering education practice and research.

Recommendations to engineering education practice are discussed in Chapters 4 and 5, and future directions for research are discussed in Chapters 3, 4, 5, and 6.

1.6 Stakeholders

This researcher study has implications for several stakeholders including researchers in engineering education, non-curricular learning researchers, engineering educators, engineering program administrators, directors of non-curricular engineering groups or programs, and engineering higher education students.

Engineering education researchers are stakeholders of this research study because this study builds on existing engineering education research pertaining to how and where engineering students learn engineering skills and content. Also, this study builds on existing research on the influence of non-curricular activities on engineering students' educational experiences and discovering explanations for such influences. The findings of this study could further help inform the design, implementation, and evaluation of non-curricular learning environments for engineering students.

Non-curricular learning researchers are also stakeholders of this research study. While limited, there is a growing body of literature focused on informal learning environments. Much of this existing literature is within the context of K-12, liberal arts, or science education. Higher education and engineering contexts are less commonly found in non-curricular learning research. Findings from this study could help build research on non-curricular learning environments, providing a unique situation and environment to existing non-curricular learning literature.

Engineering educators, administrators, and directors of non-curricular groups or programs are all stakeholders of this research study. Engineering educators and administrators have been pressured to design innovative and engaging curricula, while successfully meeting the various engineering ABET criteria. The findings of this research study could help inform engineering educators and administrators of the various opportunities outside of the classroom available to their students to experience and learn engineering skills and content, reducing the pressure to "do-it-all" inside the classroom. Directors of non-curricular programs would also be informed by this research study. Findings from this study could help inform the design, implementation, and evaluation of these non-curricular learning environments.

Finally, engineering students are one of the most important stakeholders of this research study. As previously mentioned, engineering curricular have come very comprehensive and inflexible, reducing opportunities for engineering students to personalize their education to best meet their personal academic and professional goals. As Stevens et al. (2008) have identified, students seek opportunities for navigational flexibility in their education, and participating in non-curricular learning environments is an approach to finding this navigational flexibility. The findings from the research study could help inform students' decisions of which non-curricular learning environments to participate in, based on their personal goals. Also, findings from this study could help students identify and articulate the experiences and skills they have gained through their participation in non-curricular learning environments. As stated in the previous sections, recommendations pertaining to these stakeholders can be found in Chapters 4 and 5.

1.7 Research Questions and Research Design

The purpose of this dissertation study is to better understand the educational experiences of undergraduate engineering students within informal learning environments, specifically in the form of engineering non-curricular groups or programs. The overarching research question considers how engineering non-curricular activities influence engineering students' undergraduate experiences. Table 1.1 shows the four primary research questions, as well as the data collection, analysis, and outcomes for each of the research questions.

Table 1.1. Overarching Research Question - How are engineering non-curricular activities influencing engineering students' undergraduate experiences?

Research Question		Data Collection	Analysis	Outcomes
RQ1:	*What are the defining characteristics and implications of existing educational environments designed for undergraduate engineering design learning in large research-focused universities in the US?*	Literature review	Literature review	**Manuscript 1:** Synthesis of existing literature presenting the various learning environments designed to teach engineering skills or content
RQ2:	*How do students describe their experience with engineering-related non-curricular activities?*	Observations (field notes of Ware Lab work sessions and student meetings, total of 5 hours; field notes of ID studio, total of 20 hours); Student interviews (Formula design team students, total of 7; ID engineering students, total of 2)	Inductive and thematic coding	*Informs Manuscript 2:* Understanding of student experiences/perspectives of non-curricular learning environments
RQ3:	*What are salient features of engineering-related non-curricular activities?*	Observations (field notes for 32 hours total, over 5 sites); Student focus groups (12 total focus groups, 49 total students)	Coding informed by Self-Directed Learner Autonomy (a priori coding)	**Manuscript 2:** Identification and comparison of the benefits and/or barriers of different engineering non-curricular learning environments
RQ4:	*What role do non-curricular activities play in providing engineering students navigational flexibility?*	Observations (field notes for 32 hours total, over 4 sites); Student focus groups (8 total interviews)	Coding informed by Navigational Flexibility (a priori coding)	**Manuscript 3:** Identification of if and how students find navigational flexibility within engineering curricula

To address the first research question (RQ1) a comprehensive review of the literature was conducted to synthesize the various and unique educational experiences designed to teach engineering skills and content. Findings addressing RQ1 are presented in the first manuscript (Manuscript 1, Chapter 3).

A qualitative ethnographically-informed research study was designed to address the remaining research questions (RQ2-4). A pilot study that was conducted to address RQ2 found that students valued learner autonomy offered by non-curricular activities. Informed by the results of this pilot study, additional observations and student focus groups were conducted to answer the third and fourth research question (RQ3 and RQ4). In order to explore the common experiences of students participating in various non-curricular engineering learning environments, focus groups grouped by five different research sites were employed. The five research sites were 5 different non-curricular engineering learning sites available at a southeast R1 state university: an automotive design team, a biomedical engineering undergraduate research experience, a global service learning project, an electrical engineering prototyping laboratory, and an additive manufacturing design competition. The observations and student focus groups, which were informed by a self-directed learner autonomy and navigational flexibility frameworks, were conducted in order to identify and compare the salient features of five different non-curricular engineering learning sites. Rather than individual interviews, as was done for the pilot study, focus groups provided opportunities for more dynamic conversations with participating students, identifying the common and salient features of these non-curricular learning environments. Findings addressing RQ3 are presented in the second manuscript (Manuscript 2, Chapter 4), and findings addressing RQ4 are presented in the third manuscript (Manuscript 3, Chapter 5).

1.8 Scope of Study

The goal of this research study is to identify how engineering non-curricular activities influence students' educational experiences. As such, the study was designed to qualitatively explore in detail the experiences and perceptions of students and alumni who have participated in engineering non-curricular activities. Program evaluation of the different research sites, nor student evaluation of learning outcomes, were intentions of this research study. This study was also not designed to test hypotheses of the educational effects or learning gains of students engaged in non-curricular activities. Rather, the aim of this study was to investigate the contributions and value of a unique portion of engineering students' educational experience that has been underexplored and underutilized. Non-curricular activities are known to have positive influences on students, and I believe there is little awareness and understanding of these opportunities. Additionally, while engineering students commonly engage in non-curricular activities outside of engineering (i.e. music, the arts, sports, Greek life, etc.), such activities are outside of the scope of this study. While these activities also likely play important roles in the life of engineering students, it is important to first investigate the educational contributions of non-curricular activities with engineering-specific missions.

Data collection for this study was conducted in one academic term (semester system, approximately 15 weeks) and two summer terms (two summer sessions, approximately 10 weeks). Data collection was conducted for five different research sites over the course of the three academic terms. This research study is focused on undergraduate engineering students enrolled in a R1 state university. A more thorough discussion of the research design will be done in Chapters 3, 4, and 5.

1.9 Limitations and Researcher Bias

The biggest limitation of this study is due to participant bias. Due to the scope of this study, only students who have voluntarily chosen to participate in extracurricular activities were studied. Even more, focus group and interview participants were voluntary study participants. It is possible that students who chose to participate in extracurricular activities are characteristically different than students who would have chosen otherwise. Also, it is possible that students who chose to participate in the study have had a more substantial experience than students who choose otherwise.

When I was an undergraduate engineering student myself, I was unaware of the opportunities available to me, and I was not given the encouragement I needed to pursue these opportunities. After receiving my B.S. in Mechanical Engineering, despite my academic success, I felt unprepared for a professional engineering career. As previously stated, I strongly believe in the value of extracurricular activities to students' educational experiences. I also believe that these non-curricular learning opportunities are underutilized, and lack student and administrative awareness. As Baxter-Magolda (2001) has expressed,

> "Higher education has a responsibility to help young adults make the transition from their socialization by society to their role as members and leaders in society's future. The curriculum and co-curriculum of undergraduate… educational settings are opportunities to steward this transformation." (p. 25)

My personal experience and strong beliefs present a researcher bias that might cause an exaggeration of the positive findings of this research study. In order to limit the impact of my researcher bias, it was necessary for me to take several approaches towards maintaining the study's reliability and trustworthiness. My approach to ensuring reliability and trustworthiness are further discussed in Chapters 4 and 5.

1.10 Summary

The purpose of this dissertation study is to better understand the educational experiences of undergraduate engineering students within non-curricular learning environments. This research study explores where engineering learning occurs, as well as undergraduate engineering students' experiences with non-curricular learning opportunities. Specifically, this study investigates what non-curricular groups and programs can educationally provide undergraduate engineering students by observing and interviewing students engaging in these environments. This study also aims to identify if and how engineering students find navigational flexibility within engineering curricula, and how non-curricular learning environments might provide navigational flexibility. This research study contributes to engineering education literature by providing a synthesis of undergraduate engineering learning sites and by addressing a research gap regarding non-traditional learning environments. This study is also significant to extracurricular learning literature since it addresses a gap in the literature regarding engineering-specific extracurricular learning environments in higher education.

This first chapter has provided a generalized introduction to the research study. In Chapter 2 I will discuss the theoretical frameworks used to inform this study, i.e. self-directed learner autonomy and navigational flexibility. In Chapter 3 I present Manuscript 1, which addresses RQ1. Chapter 4 presents Manuscript 2, which addresses RQ2 and RQ3. Manuscript 3, which addresses RQ4, can be found in Chapter 5. A summary of this dissertation study and directions for future research are discussed in Chapter 6.

CHAPTER 2: THEORETICAL FRAMEWORK

Taking an inductive approach to answering the RQ2 of this dissertation study – *How do students describe their experience with engineering-related non-curricular activities?* – an ethnographically-informed pilot study (Kusano & Johri, 2014; Kusano et al., 2014) was conducted with students participating in an automotive design team. Data collection involved observing students working in a university-sponsored manufacturing laboratory, which is the facility used by over 20 different undergraduate engineering design teams, as well as observing student meetings, and interviewing 7 individual students and the faculty advisor. After analyzing the pilot study data, emerging salient themes were captured. One of the most notable recurring themes among the data was 'ownership', or what I have called "student autonomy". Students' autonomy over their work, vehicle design decisions, and ultimately competition results was consistently observed and noted by interviewed students and the faculty advisor as one of the most valuable features of the Formula team experience. Students and faculty alike valued this feature of the Formula team experience, and students often reported that this sense of agency with their learning is something that is desirable yet often absent from formal coursework.

This chapter discusses two driving theoretical frameworks of this dissertation study that have emerged from the pilot study previously described. First, I will discuss the self-directed learner autonomy framework: what it is, its origins, and its relevance to addressing RQ3 (see Chapter 1). Next, I will discuss the 'Becoming an Engineer' framework presented by Stevens et al. (2008), specifically the dimension of navigational flexibility and its pertinence to addressing RQ4 (see Chapter 1). Both of these frameworks offer similar but distinguishing insights towards researching engineering student experiences in non-curricular activities.

2.1 Self Authorship

Self-authorship, or an internally defined sense of self, is an important part of students' education and derives its power from three assumptions: 1) "knowledge is complex and socially constructed", 2) "self is central to knowledge construction", and 3) "authority and expertise are shared in the mutual construction of knowledge among peers" (Baxter-Magolda, 2001, p.188). Strong self-authorship is conducive to strong life-long learning abilities (Baxter-Magolda, 2004; King et al., 2009), an essential skill demanded of modern engineers (NAE, 2005, p.55; Dutta et al., 2012). Pedagogies that foster mutual construction of knowledge have been recommended to promote self-authorship, and such educational opportunities are often found in non-curricular learning sites (Baxter-Magolda, 2001, p.328). Using the self-directed learner autonomy framework as a lens to investigate non-curricular learning sites can help identify the features that foster self-authorship. Self-directed learner autonomy framework is a framework informed by Candy's (1991) self-directed learning theory and Littlewood's (1996) learner autonomy theory, which will be discussed in more detail in the following sections.

2.1.1 Self-Directed Learning, Candy (1991)

Self-directed learning is a broad theory, with many domains relevant to adult education research. As Candy (1991) discusses, self-direction as a term signifies a number of distinct meanings, particularly when self-direction is being differentiated between self-direct as a process of learning and self-direction as an outcome of learning. The four distinct domains identified by Candy (1991) include:

> *"…"self-direction" as a personal attribute (personal autonomy); "self-direction" as the willingness and capacity to conduct one's own education (self-management); "self-direction" as a mode of organizing instruction in formal settings (learner-control); and "self-direction" as the individual, noninstitutional pursuit of learning opportunities in the 'natural social setting" (autodidaxy)." (p. 23)*

Specifically for this study, self-directed learning from the autodidaxy domain, i.e. "intentional self-education" (p. 158), has implications towards students pursuing co-curricular activities that are worth exploring. Tough (1979) first operationalized the concept of autodidaxy when he described "learning projects", which are collaborative settings where individuals intentionally seek knowledge or skills. This model of "learning projects" closely aligns with the types of non-curricular learning environments that were investigated throughout this dissertation study. Candy (1991, p. 199) describes five generalizations of autodidaxy that further demonstrate its implications towards non-curricular learning experiences:

1. Learning experiences are rarely entirely self-directed learning, but rather occur along a spectrum dependent on individual motivations and interests.
2. Learning experiences and/or outcomes viewed through a self-directed lens can rarely be anticipated or predicted; "accident or serendipity plays an important role".
3. Autodidactic opportunities are most commonly emerge from unresolved programs.
4. Learners exhibiting autodidaxy are not aware of their learning.

5. “Self-direct learning is rarely completely solitary. It often occurs in the context of a social grouping…”

Candy’s (1991) framework of self-directed learning has implications for how to promote, as well as how to research self-direct learning. Specifically for engineering education contexts, studies have sought out to measure self-direct learning readiness (Litzinger et al., 2005), as well as pedagogical approaches to promoting self-direct learning (Felder & Brent, 2003). With regard to researching self-direct learning, Candy (1991) provides a “profile of the autonomous learner”, which lists 13 characteristics of the autonomous learner (pp. 459 - 466):

- Methodical/disciplined
- Logical/analytical
- Reflective/self-aware
- Demonstrate curiosity/openness/motivation
- Flexible
- Interdependent/Interpersonally competent
- Persistent/responsible
- Venturesome/creative
- Show confidence/have a positive self-concept
- Independent/self-sufficient
- Have developed information seeking and retrieval skills
- Have knowledge about, and skill at, “Learning Processes”
- Develop and use criteria for evaluating

Additionally, Candy (1991) suggests research methodologies for investigating self-directed learning; primarily qualitative and naturalistic research methodologies that can provide "rich and varied experiences of individual self-directed learners" (p. 452). While there are important implications and suggestions from Candy's (1991) self-direct learning theory, a more finely defined framework of the autonomous learner phenomenon can provide a more specific investigation of students in non-curricular learning sites.

2.1.2 Learner Autonomy, Littlewood (1996)

The accepted definition of learner autonomy in education literature is the ability to "take charge in one's own learning" (Holec, 1981, p.3). In other words, students are empowered to have agency over what they want to learn and how they are going to learn. This is an important skill for students to have, particularly engineering students in higher education, since lifelong learning is one of the top skills expected of engineering graduates. An autonomous learner will be capable to "apply their knowledge and skills outside the immediate context of learning" (Little & Dam, 1998, p.1). More so, current and future job markets is increasingly becoming a dynamic and rapidly changing landscape, requiring engineering graduates to be more adaptable than ever (NAE, 2005).

Stemming from language education (Holec, 1979; Little & Dam, 1998), the theory of learner autonomy has been shown to have implications in other educational contexts (Benson, 1996; Yen & Liu, 2009), including engineering education (Bramhall et al., 2008). Although learner autonomy has been shown to be a positive predictor of academic achievement (Yen & Liu, 2009), this is most effective when students are provided sufficient guidance through advising or mentoring (Tinto, 1993; Benson, 1996; Bramhall et al., 2008; Yen & Liu, 2009).

Such conditions (i.e. students taking control of their learning under the guidance of a mentor and/or advisor) can often be found in non-curricular learning sites.

Littlewood's (1996) model of learner autonomy has implications towards students participating in non-curricular learning sites. The primary components of the learner autonomy framework are a "willingness and ability" to learn, where willingness derives from a learner's "motivation and confidence", and ability derives from a learner's "knowledge and skills". As described by Littlewood, each of these components of autonomy must be present in order to truly demonstrate learner autonomy:

> *"Thus, a person may have the ability to make independent choices but feel no willingness to do so (e.g. because such behaviour is not perceived as appropriate to his or her role in a particular situation). Conversely, a person may be willing to exercise independent choices but not have the necessary ability to do so…a person may feel highly motivated to learn outside class but lack the necessary knowledge or skills to organise his or her time effectively; a person may have ample opportunities to develop knowledge and skills for organising learning, but not wish to do so because he or she sees this as the teacher's role…" (p. 428)*

Created for the context of language learning, Littlewood developed a framework for developing autonomy with three domains (Figure 2.1): 1) autonomy as a communicator, 2) autonomy as a learner, and 3) autonomy as a person (p. 431).

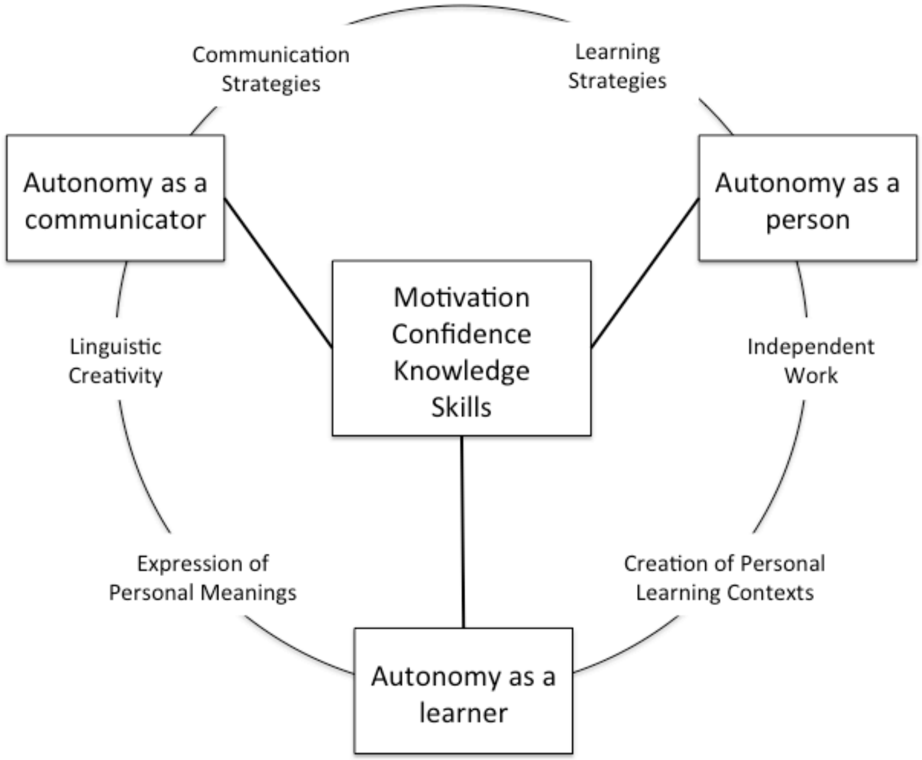

Figure 2.1. Framework for developing learner autonomy, adapted from Littlewood (1996, p. 432)

Across each domain, Littlewood discusses ways in which learner autonomy can be developed. For instance looking at the "independent work" area, Littlewood suggests that students' "willingness and ability to engage in self-directed work" should be encouraged (p. 433). Similarly, for "communication strategies", Littlewood suggests an approach to "develop students' willingness and ability to focus on communication rather than accuracy" (p. 433). Considering "learning strategies", "expression of personal meanings", and "creation of personal learning contexts", Littlewood again suggests increasing students' willingness and ability to engage in self-directed work by personalizing the content to each students' personal interests. Finally, through "linguistic creativity", Littlewood is referring to a student's ability to creatively use the content/skill learned in creative ways and situations.

Although Littlewood's framework for developing learner autonomy is presented for the context of language learning, it can also have applications to engineering education. For example, engineering educators should strive to increase engineering students' willingness and ability to engage in self-directed work, through personalized experiences, and engineering students should be just as able to apply their skills in creative ways and contexts as linguistics students (NAE, 2005; Dutta et al., 2012). Informed by the findings of this dissertation study, a framework better aligned with engineering-specific domains can be found in Chapter 4. As I observed and investigated students' experiences in non-curricular activities, I describe in Chapter 4 how learner autonomy occurs in non-curricular engineering learning sites.

2.1.3 Self-Directed Learner Autonomy

Self-direct learner autonomy merges pieces of the two frameworks previously described, as shown in Figure 2.2

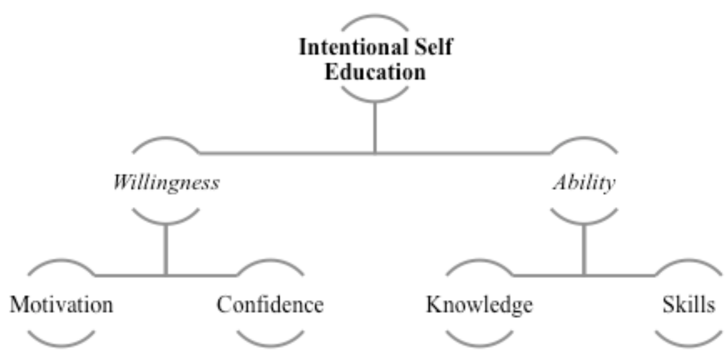

Figure 2.2. Self-Directed Learner Autonomy framework informed by Candy (1991) and Littlewood (1996).

Candy's self-directed learning theory provides the initial lens of "intentional self-education", as well as a profile of the self-directed learner that is worth investigating. Littlewood's learner autonomy framework provides a specific framework with well-defined domains that can help inform and conceptualize rich qualitative data.

On the job training programs are becoming more prevalent, and it is becoming more common for students to find job opportunities in areas that do not yet exist, requiring them to have skills that are not yet known or needed (NAE, 2005; Dutta et al, 2012). Students with well-developed and practiced self-directed learner autonomy can ideally demonstrate the necessary lifelong learning skills needed to succeed in a modern world. It has been shown that current engineering students demonstrate only average self-directed learning skills (Litzinger et al., 2005), however I believe the most rich self-directed learning experiences, which are seldom investigated, are learning opportunities that students engage in outside of the classroom.

2.2 Navigational Flexibility

Along with self-directed learning skills, an important dimension to "becoming an engineer" is a student's access to "navigational flexibility" through engineering curricula (Stevens et al., 2008). Stevens et al. (2008) present a framework that describes students' experiences through engineering curricula, referred to as Becoming an Engineer. This framework includes three dimensions: 1) the development of accountable disciplinary knowledge, 2) forming an engineer identity, and 3) navigational flexibility through engineering education (p. 356). Based on the results of the pilot study described earlier in this chapter, the third dimension of Becoming an Engineer, navigational flexibility, has important implications that helped inform this dissertation study on non-curricular learning sites.

By navigational flexibility, Stevens et al. (2008) are referring to the educational routes students take to successfully demonstrate accountable disciplinary knowledge (i.e. "actions that when performed are counted as engineering knowledge", p. 357). Stevens et al. (2008) claim that individual students take unique routes through engineering education, differentiating between "official routes" and "unofficial routes", as well as "unofficial strategies" to go through the official routes (p. 361). Official routes are those that are officially sanctioned through institutional curricular requirements. He further describes three milestones that students go through to help identify their educational pathways: 1) goals/interests, 2) horizons of observation, and 3) critical transitions through obligatory passage points, as shown in **Error! Reference source not found.** (Stevens et al., 2008). Goals/interests refers to when students identify their goals/interests and intentionally pursue some educational experience to address these goals/interests (p. 361). Horizons of observation refer to when students "develop an understanding of possible futures and increasingly identify themselves with these futures" (p. 363). Critical transitions through obligatory passage points refers to the significant changes seen in students' developing engineering identities as they go through institutional rites of passage (p. 357).

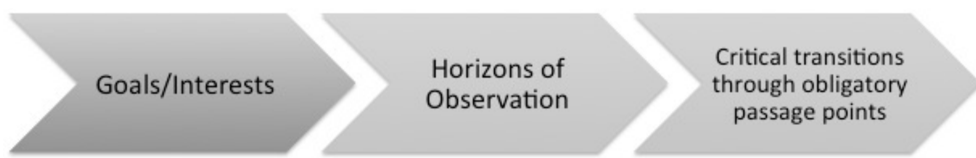

Figure 2.3. Observed Milestones of Students' Official or Unofficial Educational Routes, adapted from Stevens et al. (2008)

Stevens et al. (2008) present a few individual cases as examples of students who display these different educational pathways. For example, the authors describe a student who struggled to be accepted into an engineering program at a large public university, but while working through his courses in a pre-engineering program in attempts to raise his GPA, the student was offered an opportunity to work in a mechanical stress testing facility. Although the student's GPA continued to be below an acceptable threshold, the student was eventually admitted into the engineering program because of his extensive experience working in an engineering research lab. Once the student was officially admitted to the engineering program, finally being institutionally identified as an engineer, the student became of the top students in his engineering classes, and was quickly recognized and selected for a prestigious engineering co-op.

This student's story is one that Stevens et al. (2008) classify as an "unofficial route" through engineering education. However, they also make note that although this student can be considered a successful case, his unique educational experience is not the only viable pathway to successfully becoming an engineer. Rather, they argue that students should have the flexibility to navigate through engineering education in ways that will be most advantageous to students. Rigid institutional structures can result in students leaving engineering programs (and other STEM fields), whereas more flexible institutional structures can account for student successes (Stevens et al., 2008, p. 364).

Others in the engineering education community have considered the implications of navigational flexibility in engineering education. For instance, focusing on issues of persistence, engagement, and migration in engineering education, Ohland et al. (2008) and Adams et al. (2011) have noted that navigational flexibility encourages students interested in migrating into engineering. Others have considered the contextual factors that impact conceptual knowledge (Streveler et al., 2008; Godfrey & Parker, 2010). A student's successful navigation through engineering education by way of non-curricular experiences might be linked to strong self-directed learning since students choose the non-curricular experiences they wish to engage in. However, I believe students wishing to find navigational flexibility, and a student's successful navigation through engineering education via unofficial routes is a distinct phenomenon worth investigating.

2.3 Summary

Informed by the results from a pilot study that openly investigated salient features of non-curricular learning sites, the full-scale study conducted for this dissertation was guided by two emerging themes. First is a self-directed learner autonomy framework that was used to help understand and capture engineering students' experiences in non-curricular learning sites. Second is a navigational flexibility framework that was used to help understand and capture the role of non-curricular learning sites as students find unique ways to navigate through institutional structures and engineering curricula in order to achieve their academic and professional goals. Together, these two distinct frameworks helped provide a deeper understanding of the influence non-curricular learning sites have on engineering students' academic and professional development, as will be further discussed in Chapters 4 and 5.

CHAPTER 3: UNDERGRADUATE ENGINEERING DESIGN LEARNING IN THE UNITED STATES: A RESEARCH REVIEW

3.1 ABSTRACT

Background In response to calls for more innovative and engaging educational experiences, various pedagogies and educational strategies for teaching engineering design at the undergraduate level have been developed and implemented. There has been extensive research on the educational methods and influences of engineering design education, but there is little literature synthesizing this work with implications for engineering design teaching and research.

Purpose This literature review seeks to identify and synthesize the literature on engineering design learning at the undergraduate level in large research-intensive institutions in the U.S., with implications for practice and future research on engineering design learning. The following two questions guided our review: 1) What are the defining characteristics of existing educational environments designed for undergraduate engineering design learning in large research-focused universities in the US, and 2) What are the implications of different engineering design learning environments and experiences to large research-focused undergraduate engineering program structures?

Scope/Method After identifying 776 research articles that pertained to the broad topic of engineering design education, we identified 74 articles that specifically met our criteria for the scope of the review (i.e. post-EC2000; studied undergraduate engineering students; studied undergraduate large research-focused engineering programs in the US; purpose of study is to describe an engineering design experience or educational approach, or to understand a phenomenon relevant to engineering design learning). We first sorted through the selected 74 articles using content analysis to determine categories that answered our first research question;

examples from the literature that exemplify the categories are presented. We then reviewed the 32 of the 74 articles that were explicitly research-focused articles, again using examples from the literature, to help answer our second research question.

Conclusions A variety of approaches to teaching engineering design in both traditional and nontraditional educational settings have been effectively implemented. Strategies that involve authentic and longer-term engineering design experiences tend to be the most impactful in terms of student outcomes and perceptions; however those experiences are not always implementable at larger scale. More traditional educational approaches to engineering design learning, though less impactful, are still effective delivery methods for introducing key aspects of engineering design education (e.g. modeling, global/societal/economic/environmental factors, communication skills). The earlier in their career that students are exposed to engineering design, and the more consistently they participate, the better the learning outcomes (i.e. communication skills, teamwork skills, innovative and critical thinking). There is also a large gap in the existing engineering education literature with regard to more non-curricular learning experiences, such as learning in designed settings, outreach learning, learning media, and everyday learning.

3.2 Introduction

Since the establishment of ABET's EC2000 in 1997, the engineering education community has been striving to identify and implement innovative engineering education pedagogies. As a result, there are various educational environments intentionally designed to teach undergraduate students engineering content and skills, each with the goal of inspiring and developing innovative professional engineers. Engineering students in the U.S. of the last nearly 15 years have had more opportunities to experience hands-on engineering design, in addition to traditional theoretical engineering, while going through their undergraduate career. In this paper, we review existing scholarship, post-EC2000, from the top engineering education journals with the goal of identifying and categorizing the various undergraduate engineering learning sites in the United States. We will also discuss the implications that this body of literature has for engineering design education practice and for future research work on engineering design learning.

Learning can occur in many different ways and in many different environments. This is not a novel or controversial revelation, as indicated by the innumerable reports, presentations, discussions, and scholarship towards designing, implementing, and assessing educational environments (Bransford, 2000; NAE, 2005; Bell et al., 2009; Ambrose et al., 2010). Engineering education has a history of evolving pedagogies, attempting to adapt to changes of societal demands (Seely, 1999). Most recently, since the establishment of ABET's EC2000 in 1997, there has been another 're-engineering' (Seely, 1999) of engineering education. Modern engineering education goals include designing and implementing innovative and engaging educational experiences for engineering students, in hopes of not only attracting and retaining engineering students, but also in hopes of developing and inspiring the future members and leaders of the engineering community (NAE, 2005; Jamieson & Lohmann, 2009; Sheppard et al., 2009). In response to these calls for innovative and engaging education experiences, various learning sites have emerged among existing educational environments, all intentionally designed to teach engineering content and skills.

This literature review seeks to identify and synthesize the different engineering design learning strategies and sites available to undergraduate engineering students. Engineering design-learning sites are educational spaces designed with the intent to provide lasting experiences and knowledge on engineering design content and skills. A content analysis approach was used to address the primary questions:

1. What are the defining characteristics of existing educational environments designed for undergraduate engineering design learning in large research-focused universities in the US?
2. What are the implications of these different engineering design learning environments to large research-focused undergraduate engineering program structures?

By addressing these questions, this literature review will provide a synthesis of engineering design learning sites that can facilitate the identification of the gaps present in currently available educational opportunities for engineering students, as well as gaps in engineering education research. This analysis of engineering design learning sites can also help inform the growing efforts toward enhancing personalized learning opportunities for students (Stevens et al., 2008; Johri & Olds, 2011).

3.3 METHODS

A content analysis approach was employed to review the relevant engineering education literature (Krippendorff, 2012). This approach has been effectively used to synthesize literature for other engineering education research (Beddoes & Borrego, 2011; Borrego et al., 2013). This section will discuss in detail the data sources and analysis used for this literature review. First, it is important to define the scope of this literature review.

3.3.1 SCOPE

This literature review is focused on literature relevant to engineering design education, using the *Education Research Complete (ERC)* database to identify relevant literature. The *ERC* database is a comprehensive database of education and engineering education journal publications and conference proceedings, including the leading publications in the field. To maintain a manageable range of analysis, this review is limited to literature that was directly relevant to undergraduate engineering design education in large research-focused institutions in the United States. Engineering design experiences are a growing trend in undergraduate engineering curricula (Dym et al., 2005), and many out-of-classroom learning experiences for engineering students are focused on design experiences (Gerber et al., 2012). This analysis will be focused on engineering education studies post-EC2000, so literature that was published between the years 2000 and 2013 will be included for practical reasons while remaining framed relative to ABET. Any literature pertaining to engineering education had the potential to be included in this review, so any of the 29 engineering disciplines with ABET accreditation criteria could have been represented. The review is exclusively for engineering education research settings, therefore science, technology and mathematics, that is, studies from other STEM areas, were not incorporated in the review.

Selection criteria included:

Studied undergraduate engineering students This excludes studies on students in K-12, graduate engineering students, and practicing engineers.

Studied undergraduate large research-focused engineering programs in the US This excludes studies on students from small teaching-focused institutions, community colleges or other non-four-year programs, and institutions outside of the United States.

Purpose of study is to describe an engineering design experience or educational approach, or to understand a phenomenon relevant to engineering design learning This excludes studies focused on developing and validating assessment instruments for assessing students' learning outcomes.

3.3.2 Data Sources & Analysis

The *Education Research Complete* database was used to find relevant literature. This database indexes journals, books, book chapters, case studies, essays, interviews, conference proceedings, product reviews, and experiments in all education fields. Restricting the search to peer-reviewed engineering education journal articles and conference proceedings from the years 2000-2013, titles, abstracts, and keywords were all reviewed using search terms such as *design education, design learning site, design classroom, design learning environment, formal design learning, informal design learning, traditional design learning, non-traditional design learning, design education curriculum, non-curricular design education, out-of-classroom design learning, extracurricular design education, co-curricular design education,* among other similar terms and phrases. Relevant articles were collected and saved in an EndNote database.

After identifying the qualifying journal articles and conference proceedings, each article was read in its entirety. An additional researcher was asked to assist with the review of qualifying literature, in order to find agreement on an appropriate coding and categorization protocol. Contextual classification of the data was used to categorize the articles (Krippendorff, 2012). Discrepancies were discussed until the researchers reach an agreement on the categorization of the articles. The findings, discussions, recommendations, and implications presented in the articles were compared in order to identify trends or patterns with the various learning environments.

3.3.3 LIMITATIONS

The limitations of this literature should be noted. The largest limitation of this review is the limited time frame of 13 years. Scholarship regarding the design, implementation, and assessment of engineering education and its learning environments has been actively presented for decades, long before EC-2000. That said, EC-2000 marks a significant milestone in modern engineering education, and significant contributions and systematic changes have been made in the engineering education community in the past thirteen years. Post-2000, engineering education became a more substantial and rigorous research field. Additionally, the engineering education community became more actively concerned about ABET criteria, particularly regarding active design-based learning (NRC 2005; Borrego & Bernhard, 2011). Also, the primary focus of this review is undergraduate education, specifically large engineering programs, in the United States. We recognize that engineering design learning occurs at smaller institutions; however the context within which student learning occurs at smaller institutions is typically not comparable to that at larger institutions. It is our belief that larger institutions, where it can be more costly and challenging to implement engaging engineering design experiences for a large population of students, can particularly benefit from the existing literature on engineering design learning experiences and research.

While these limitations result in a relatively exclusive review, a review of this sort is a gap in current engineering education scholarship. For a more comprehensive understanding of the history of engineering design in the engineering curriculum, and the dimensions of engineering design thinking, we direct readers towards the seminal piece in the *Journal of Engineering Education* by Dym, Agogino, Eris, Frey, and Leifer (2004). This review should be seen as a continuation of the dialogue Dym and his colleagues began on pedagogical models of engineering design teaching, in which they solely focused on project-based learning. It is our hope that our discussion here, as well as the limitations of this review, encourages future research pursuits on identifying, understanding, and characterizing engineering design educational contexts not addressed by this review.

3.4 Results

Using the guiding research questions and the keyword search described in the previous sections, our initial search of the *Education Research Complete* database resulted in 776 scholarly journal articles. Considering the titles, keywords, author affiliations, and abstracts, we then narrowed down the pool of articles further to 215 articles. We removed articles that were outside of the criteria discussed in the previous sections. Based on a deeper analysis of the abstracts, the resulting 215 articles were then further analyzed to ensure that the search criteria were met, of which 74 articles were found to meet the specific criteria previously described. To identify the characteristics of the various pedagogies towards engineering design, the 74 articles were sorted into three broad and exclusive categories: formal design learning, nontraditional learning design, and design learning implications, as shown in Table 3.1. A full list of the categorized articles can be found in Appendix E.

Articles in the formal design-learning category describe formal engineering design educational environments, e.g. capstone design courses, first-year engineering courses, courses developed specifically for engineering design learning. Note that by "traditional engineering design learning" we mean curricular, in-classroom experiences. These are classroom experiences that students undergo upon enrolling in the course, often as part of a degree requirement.

Table 3.1. Categorized Articles

Category	Description	# Articles (Example Citations)
Traditional design learning	Articles describing formal engineering design environments (e.g. capstone, FYE, engineering design courses, etc.)	27 (Barr et al., 2000; Williams et al., 2010; BanneRot et al., 2010)
Nontraditional design learning	Articles describing nontraditional methods for delivering engineering design education (e.g. service learning projects, virtual learning, competition experiences, etc.)	13 (Matthews & Spencer, 2001; Coyle et al., 2005; McKenna et al., 2007)
Design learning research	Articles explicitly describing research focused on engineering design education	34 (McNair et al., 2008; Gerber et al., 2010; Zoltowski et al., 2012)

Articles in the nontraditional design learning category describe nontraditional approaches to teach engineering design, e.g. service learning projects, virtual learning experiences, or design competition experiences. By "nontraditional engineering design learning" we are referring to non-curricular learning opportunities, or novel classroom-based learning opportunities (i.e. virtual laboratories), or classroom-based learning opportunities that are not curricular requirements. Articles in the design learning implications category explicitly described a phenomenon and/or practical implications that were discovered by research on engineering design education. To organize the implications to practice and research of engineering design learning, the 32 articles in the 'design learning implications' category were further distributed into five distinct categories, as shown in Table 3.2.

The following sections first characterize engineering design educational strategies in traditional and non-traditional learning environments, as well as discussions regarding the implications of the literature for practice. Next a synthesis of engineering design education research, categorized by the sub-categories listed in Table 3.2 will be presented, followed by a concluding discussion of the implications of the literature for research.

Table 3.2. Categorization of Design Learning Implications

Sub-Category	# Articles	Example Citations
Multidisciplinary/Collaboration	4	(Laeser et al., 2003; Hotaling et al., 2012)
Design for Society	5	(Gerber et al., 2010; Zoltowski et al., 2012)
Design Process/Ideation	13	(Atman et al. 2007; Daly et al., 2012)
Skill Development//Scaffolding	7	(Marra et al., 2000; Manuel et al., 2012)
CAD/Modeling	3	(Dixon & Johnson, 2011; McKenna & Carberry; 2012)

3.4.1 Characterizing Engineering Design Educational Strategies

What Is Engineering Design? The most widely accepted definition of engineering design in engineering education literature is that engineering design is an iterative process used to address engineering challenges (Dym et al., 2005; Jonassen, 2014). As defined by Dym et al. (2005):

> *"Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints." (p. 104)*

The iterative process of engineering design traditionally consists of five phases: problem definition, conceptual design, preliminary design, detailed design, and final design (Dym et al., 2004, 2005; Jonassen, 2014). With regard to understanding engineering design and the engineering design process, there is an extensive body of literature discussing the ways and processes engineers, from professional workplaces to novice college students to K-12 learners, approach and learn engineering design (Bucciarelli, 1994; Little & Cardenas, 2001; Atman et al., 2008; Anderson et al., 2010; Johri, 2010; Trevelyan, 2010; Schilling; 2012; Jonassen, 2014; Stevens et al., 2014). Realizing the importance of engineering design, and more importantly the lack of experience engineering students have with engineering design, the engineering education community quickly sought out various approaches and interventions to now include engineering design in the engineering curriculum (NAE, 2005; Crawley et al., 2007; Sheppard et al., 2008, 2009). As will be described in the following sections, in the past decade there have been a variety of approaches and interpretations of how engineering design should be taught. Despite Dym's seemingly straightforward definition of engineering design, teaching engineering design appears to require iterative and diverse pedagogies reflective of the iterative and complex process that engineering design tends to be.

HOW IS ENGINEERING DESIGN TAUGHT? Dym et al. (2014) argue that the most productive approach to teaching engineering design is through project-based learning. However, there are many other pedagogical strategies, in and outside of the classroom, to teaching engineering design. In an attempt to comprehensively categorize design education approaches, Dorie et al. (2012) created taxonomy of formal and informal learning environments in engineering, hoping to "provide common schema for considering the differences between informal and formal environments" (p. 1):

- Curricular Learning (anything during normal school hours)
- Learning in Designed Settings (science centers, museums, zoos, aquariums)
- Extracurricular Learning (tutoring, afterschool programs, design competitions, etc.)
- Outreach Learning (developed through an outside source)
- Learning from Media (books, television, games, social network, internet)

- Service Learning (e.g. Engineers Without Borders, Engineering for a Sustainable World)
- Everyday Learning (play, family conversations)
- Professional Learning (workplace learning, professional societies, internships, co-ops)

Specifically considering undergraduate engineering education in the U.S., the most common traditional educational environments found in the literature for this review include capstone design courses, first-year engineering courses, and industry-sponsored or industry-based courses for undergraduate engineering students. The most common nontraditional educational environments included studio-based environments, virtual environments, service-learning experiences, and competition-based experiences. The following sections will discuss various examples in the literature that exemplify the characteristics of traditional and nontraditional engineering design learning.

TRADITIONAL ENGINEERING DESIGN LEARNING. One of the most widely studied and accepted approaches to engineering design learning in a traditional setting is capstone design courses, which are often offered at the senior-level of a student's undergraduate career (Jonassen, 2014). Capstone courses are typically long-term (one full term, up to a year) design projects, where students are expected to define an engineering problem, research and develop solutions, and prototype, showcase, and/or communicate the final solutions (Manuel et al., 2008; Al-Rizzo et al., 2010; Leake et al., 2010; Wolcott et al., 2010; Barry et al., 2011; Norback et al., 2014). A growing trend with capstone design courses is offering industry-sponsored projects, in which engineering companies or government agencies offer resources and an authentic challenge for senior-level students to experience engineering design (Guardiola et al., 2013; Norback et al., 2014). That apparent trend in the prioritizing goal of capstone design courses is to provide students the opportunity to experience and find solutions for *authentic* engineering design problems (Barry et al., 2011; Guardiola et al., 2013; Jonassen, 2014)

Similar to capstone design courses is first-year engineering courses, often referred together as “cornerstone” courses (Dym et al., 2005; Atman et al., 2014). As the engineering education community has begun to better understand the variety of factors that influence retention and engagement issues, the necessity of offering large and diverse groups of first-year engineering students meaningful learner-centered experiences has become a priority (NAE, 2005; Lichtenstein et al., 2014). Another influence to the growing trend of having design-based first-year experiences was the engineering community’s emphasis on better preparing students for the engineering workplace. Engineering educators hoped to offer more authentic learning experiences that better represent workplace problem solving, however the community agreed that waiting until the senior year to introduce and teach engineering design was no longer acceptable (NAE, 2005; Dym et al., 2005; Jonassen, 2014). First-year engineering design learning tends to lean on team- and project-based activities that engage students in simplified design challenges, often based on authentic engineering challenges (Barr et al., 2000; Ropers-Huilman et al., 2005; Lau, 2007; Terpenny et al., 2007, 2008; Williams et al., 2010; Daly et al, 2012; Dalrymple et al., 2013). Commonly discussed approaches for teaching design at the first-year level include product archaeology and reverse engineering pedagogies (Barr et al., 2000; Dalrymple et al., 2013; Kremer et al., 2013; Moore-Russo et al., 2013). First-year courses are also used as a venue to teach about sustainability in engineering design (Lau, 2007; Wolcott et al., 2010), service-learning opportunities within engineering design (Ropers-Huilman et al., 2005), and design heuristics (Daly et al., 2012).

Cornerstone courses are not the only traditional learning environments discussed in the engineering design learning literature. Other courses offered to sophomore and junior-level students, as well as courses that might act as electives for upper-level engineering students, have also been discussed in the literature (Tsang, 2000; Reeder, 2005; Boyette, 2007; Lewis et al., 2007; Roman, 2007; Lackey, 2011; Liu et al., 2011; Birnie et al., 2012; Kremer et al., 2013; Carberry & McKenna, 2014). These courses are typically are taught with the specific goal of teaching students about engineering design to help bridge the gap between first-year and capstone experiences (Tsang, 2000; Lewis et al., 2007). Non-cornerstone engineering design courses are most prominently focused on providing students "hands-on" project-based experiences (Tsang, 2000; Boyette, 2007; Birnie et al., 2012). In general, the purpose of these courses is to refine students' approach to the design process and engineering design by introducing more advanced design topics such as the use of modeling (Carberry & McKenna, 2014), meeting the needs of industry stakeholders (Lackey, 2011), and having laboratory experience (Tsang, 2000). These studies exemplify how and why engineering design learning needs to occur beyond the cornerstone courses, but rather all throughout the engineering curriculum. As Boyette discusses:

> *"We* ***owe*** *our students and society, to provide or teach the tools necessary to be productive professionals. As important, we should* ***want*** *our students to finally and fully experience the thrill of creative design that will make them desire a career in the profession. Based upon the application of science, engineering is the profession where individuals can exercise their creative potential for the benefit of society. Engineering design is a noble undertaking needed now more than ever." (P. 634)*

NONTRADITIONAL ENGINEERING DESIGN LEARNING. Nontraditional engineering design learning, or learning experiences that do not represent traditional curricular experiences, are also a possible avenue for engineering students to learn engineering design. Although these studies or discussions of nontraditional learning experiences are not as prevalent in recent engineering education literature, there have been a number of studies discussing educational approaches outside of the curricular norms in engineering.

With a growing trend towards implementing technology in the classroom, virtual environments for engineering design learning has been shown to be a viable approach to teaching engineering design, particularly for large classes with limited resources (Renshaw et al., 2000; Harmon et al., 2002; Koretsky et al., 2011; Parkinson et al., 2011; Okutsu et al., 2013). Virtual laboratories or design-learning spaces have successfully been implemented for capstone experiences for various engineering disciplines (Koretsky et al., 2011; Parkinson et al., 2011). Koretsky et al. (2011) compared "industrially situated" virtual capstone laboratories to physical laboratories, finding that while neither delivery method was better, virtual laboratories might afford a broader opportunity for students' experiences. Parkinson et al. (2011) used virtual capstone experiences as an approach to provide students with global engineering design experiences by having students interact with other engineering students around the world, which might not have been possible otherwise. In other engineering education contexts, such as in a second year aerospace engineering design course and a senior-level environmental engineering design project, researchers found that virtual learning experiences are neither better or worse than physical learning experiences, but that virtual learning environments provide broader opportunities for engineering students that might not otherwise be available (Renshaw et al., 2000; Harmon et al., 2002; Okutsu et al., 2013). Other technologically driven approaches to engineering design learning include the use of computer-based tools to help students learn engineering design skills, such as process competence, collaboration, constructive skills, and reflective practice (Finger et al., 2007), or utilizing models to inform engineering design (Butler, 2009).

Another nontraditional engineering design learning experiences described in the literature is having designed spaces specifically for students to learn and explore engineering design. For example, Evans et al. (2007) describe an entrepreneurial program for engineering students called “The Idea to Product Program”. This was a student led program that allowed students to learn the necessary language and skills needed to succeed in engineering design from an entrepreneurial prospective, specifically within the realm of marketing, financing, and intellectual property development, as well as communication and team management skills. Similarly, McKenna et al. (2007) describe the Institute for Design Engineering and Applications (IDEA), which is specifically designed to offer students an “Engineering Design Certificate Program” as a way to encourage students to apply their engineering knowledge in creative and innovative ways.

Competition-based and service-learning design experiences are another common nontraditional design learning approach. There have been a variety of engineering design competitions discussed in the literature, both in and out of the classroom, oftentimes sponsored by industry or government agencies (Matthews & Spencer, 2001; Muske et al., 2006). Similarly, service-learning design projects have been used as an approach to teach and experience engineering design (Coyle et al., 2005; Dinehart & Gross, 2010). For example, at Purdue University, students can join multidisciplinary engineering service-learning design teams at any point during their undergraduate career through the EPICS (Engineering Projects in Community Service) program (Coyle et al., 2005). Service-learning projects have also been used to successfully offer alternative capstone design experiences (Dinehart & Gross, 2010). What tends to be unique about competition-based or service-learning design experiences is that because of the inherent nature of design competitions and service-learning projects students are able to experience a whole engineering design process, i.e. problem definition, conceptual design, preliminary design, detailed design, and final design.

3.4.2 Engineering Design Education Research

Staying aligned with the idea of research-to-practice (Jesiek et al., 2010), it is important to also identify and characterize the various research studies on engineering design. Previous experiences and research-based findings discussed in the engineering design literature provide valuable contributions to the understanding of the practice of teaching engineering design, as well as to research on engineering design learning. The following sections will categorize the various types of research that has been done on engineering design learning in large undergraduate institutions.

Multidisciplinary/Collaboration. A common characteristic of professional engineering design work is that it is an often multidisciplinary and/or collaborative process (Dym et al., 2008; Kolmos & de Graff, 2014; Nersessian & Newstetter, 2014). Realizing this, the engineering education community has sought to include and evaluate multidisciplinary and collaborative aspects in engineering design education. For example researchers studying a senior capstone design course at Georgia Tech hypothesized that students with multidisciplinary capstone design experiences would have better outcomes, measured by job placement and independent evaluation by industrial professionals, than students with monodisciplinary capstone design experiences (Hotaling et al. 2012). The researchers confirmed their hypothesis, and also found that their hypothesis was especially true for biomedical engineering students. Hoping to better prepare students for interdisciplinary challenges before entering senior capstone design, McNair et al. (2008) considered the influence of being exposed to global interdisciplinary communications through a course offered to junior-level students. This mixed-methods study was inconclusive, as quantitative results showed no indication of differences between control and treatment groups, however qualitative data indicated that the treatment group of students would be more readily able to collaborate in virtual teams and communicate their expertise outside of technical laboratory or classroom contexts. Also awareness of the importance of social skills in engineering was improved with the treatment group, based on qualitative data. A similar study by Muske et al. (2006), introduced multidisciplinary experiences to freshman-level students, also finding that students were more aware and more confident about working on multidisciplinary design teams after the experience.

DESIGN FOR SOCIETY. Recognizing that many engineering students are motivated by a desire to contribute to societal needs, particularly female and under-represented engineering students (Ropers-Huilman et al., 2005; Coyle et al., 2006; Oehlberg et al., 2010; Lichtenstein et al., 2014), engineering educators have also used designing for society as an avenue for teaching engineering design. This might include community needs/service projects (Ropers-Huilman et al., 2005; Kilgore et al., 2007), sustainability projects (Oehlberg et al., 2010; Gerber et al., 2010), and human-centered design projects (Zoltowski et al., 2012). Design tasks primarily focused on benefiting society and responding to societal needs have been shown to improve students' awareness of the impact engineering can have in terms of environmental and societal factors (Zoltowski et al., 2012). Community and sustainability focused projects also improve students' understanding of the principles of designing in environmentally-conscious and socially responsible ways, however students still struggle to implement these principles into their own design work (Gerber et al., 2010). Design tasks focused on designing for societal needs have been shown to be relatively effective and simple to implement in design courses of all levels in the undergraduate curriculum, helping to improve student engagement, communication and teamwork skills, and awareness of the role of engineering in society (Astin & Sax, 1998). Outside of classroom experiences, non-curricular service learning experiences (e.g. Engineers Without Borders, EPICS) have a larger impact in terms of leadership development, long-term student participation, and student retention (Astin & Sax, 1998; Coyle et al., 2006). However, conclusive research on the impact of service learning has on students, engineering education, and related stakeholder is still limited (Swan et al., 2014).

Design Process/Ideation. Studies about how students approach engineering design (Atman et al., 2007, 2008; Bailey, 2008; Cardella et al., 2008; Lawanto et al., 2013), strategies to teach or assess engineering design (Dym et al., 2005; Magee & Frey, 2007; Ohland & Summers, 2007; Svihla et al., 2012; Pembridge & Paretti, 2013), as well as studies specifically focused on the ideation, or concept generation, phase of engineering design (Daly et al., 2012; Currano & Steinert, 2012; Tolbert & Daly, 2013) are one of the most common dialogues found in engineering education literature for the context of design education at the undergraduate level. Dym et al. (2005) provide a comprehensive review of the current state of engineering design learning by defining engineering design, reviewing research on project-based learning, identifying questions related to engineering design, and finally by providing recommendations for future research and action on engineering design, concluding that "…the most important recommendation is that engineers in academe, both faculty members and administrators, make enhanced design pedagogy their highest priority in future resource allocation decisions." (p. 114). The following examples help demonstrate how some have approached enhancing design pedagogy.

Studies focused on how students approach engineering design are primarily comparative studies, such as the comparative work done by Atman and her colleagues comparing novice and experts. Using a verbal protocol analysis after asking engineering students (novices) and practicing engineers (experts) to complete a given playground design task, Atman et al. (2007) found that experts spent a significantly longer time on the task than engineering students, using significantly more information gathering and considering significantly more objects. Atman and her colleagues completed a similar study (Atman et al., 2008), comparing freshman and senior level engineering students, specifically the breadth of which the two groups of students approach problem scoping. This study found that both freshmen and senior students consider broad contextual factors when identifying and scoping a problem, and that there is growth in terms of the quantity and breadth in problem-scoping, however there was variation within student groups. Similar studies focused on identifying and characterizing how students approach engineering design by Bailey (2008), Cardella et al. (2008), and Lawanto et al. (2013) have found similar results as Atman and her colleagues.

Studies geared towards finding interventions or strategies to help teach engineering design have also been prominent in the engineering education literature. For example, Ohland & Summers (2007) describe how they used three different hierarchical models to guide engineering design learning: Vygotsky's model, Haile's model, and Egan's model. In applying these models, the authors recommend designing engineering design education by beginning with concrete examples then have students transfer their knowledge, generalizing their knowledge, and then extending the design process to other applications (Ohland & Summers, 2007). Svihla et al. (2012) considered how task authenticity and students' ability to negotiate their learning influenced engineering design learning. The authors found that students do not consider client or user needs when working on kit-based design projects, as compared to authentic re-design design projects, and students' ability to negotiate their own learning resulted in higher quality and more innovative design. Also, authentic design experiences (sponsored project, or re-design) can help students develop their procedural knowledge of design (Svihla et al., 2012). Another approach to teaching engineering design is the use of design heuristics, such as how Magee & Frey (2007) describe. Magee & Frey (2007) focused on the role of the use of heuristics during design, and the influence using design heuristics can have on design outcomes. The study looks at a module on experimentation in engineering design, which is offered as part of the Undergraduate Practice Opportunity Program at MIT, and in which over 300 students have participated. Upon observation, the authors found that "fast and frugal heuristics" were an effective strategy to teaching engineering design.

Other examples of the use of design heuristics include studies that employed design heuristics to facilitate the ideation or concept generation phase of engineering design. For example, Kotys-Schwartz et al. (2014) described how they effectively used design heuristics, through the use of 77 design heuristics cards, as a method for guiding students through engineering design ideation and concept generation. The 77 design heuristics cards emerged from a previous study by Daly et al. (2012), where the authors investigated how engineering students and engineering professionals generate ideas during engineering design, particularly focusing on the use of "product characteristics to define concepts, and how previous concepts were transformed into new solutions" (p. 601). Using think-aloud protocols and concept sketching during an experimentally set design task, as well as interview data, over 60 strategies for generating concepts emerged, including specific design heuristics that could be taught for effective design ideation. Other studies have investigated how students perceive creative opportunities during design tasks, and how those perceptions influence design decisions (Tolbert & Daly, 2013), recommending instructors to be conscious about including creativity (if it is a valued element) among rubrics or other grading schemes, and that instructors should explicitly discuss consequences (negative and positive) of risk taking, as well as provide support and advice on ways to explore design ideas. Similarly, Currano & Steinert (2013) discuss a preliminary study of the role of reflective practice during creative ideation. Although it is still in its preliminary stages, Currano & Steinert present a promising approach for characterizing and understanding how reflective practice can influence the design process for different individuals and different design tasks.

Skill Development/Scaffolding. Other research on engineering design learning has largely focused on the necessary skill development and scaffolding needed to properly guide students as they are introduced and work on engineering design projects. For example, researchers have used specific frameworks to help understand (Marra et al., 2010) and/or design (Panchal et al., 2012) engineering design experiences. Marra et al. (2000) employed the Perry model to investigate, using a mixed methods approach, the impact of a first-year engineering design course on students' intellectual development. The study found that students who experience first-year design courses do grow intellectually, based on the Perry model. Looking more closely at ways of designing engineering design experiences, Panchal et al. (2012) present a possible framework based on the expectancy-value theory of achievement motivation. The framework was implemented in a junior level mechanical engineering system dynamics course at Washington State University, and data included assessment of student-teams' design projects, and students were surveyed at the end of the semester. The study found that motivation was positively and significantly correlated with expectancy beliefs on mathematical skills and the students' values of the project, which also positively & significantly correlated with performance and learning outcomes. Additionally, at the beginning of the course students' believed their Matlab skills were adequate for the project (high expectancy), however after working the project students realized their Matlab skills were not sufficiently adequate for the project (spending more time on debugging and changing code), implying that students need to put their skills into practice in order for students to be self-aware of their own skill development.

There have also been a variety of approaches towards scaffolding students' design experiences. Cheville (2010), using quantitative and qualitative data, showed that using the Vygotsky cycle model for an electrical engineering senior design capstone course allowed students to pursue divergent thinking, reflective practices, and ownership over design roles. However, the Vygotsky cycle model did not help students demonstrate perceptions of the process of design as creative, nor did they consider their projects among a larger context. Trying to better support students' technical innovation in a capstone design course, Manuel et al. (2012) used a coaching model in a junior level materials design course at Northwestern University. The model was a hierarchal model, with an instructor overseeing graduate student coaches who oversaw undergraduate student teams that were in the materials design course. Both undergraduate and graduate students were surveyed, and the graduate students were interviewed. The study found the importance of having a strong "personal-connection" between students and coaches does support students' innovative skill development while working advanced engineering design projects. However, the authors caution that their results were mostly inconclusive due to small sample sizes and self-reporting of perceptions.

Lebeau et al. (2014) also looked at influences on students' professional skill development, by surveying alumni who had recently experienced an Integrated Design

Engineering Assessment and Learning System (IDEALS). IDEALS integrated professional skills learning through assessment modules in a senior capstone design course at a number of universities. The study indicated that alumni felt that the IDEALS professional development and teamwork modules somewhat enhanced their professional skills, reflective skills, knowledge, and abilities in professional settings. The IDEALS modules were most effective when instructors consistently and regularly encouraged or explained how to use the IDEALS modules throughout design projects. Other studies support that regular and consistent exposure to engineering design experiences that are somewhat scaffold, as expected, has more of an impact on students' professional and skills development (Moor et al., 2001; Stamps, 2013)

CAD/MODELING. Having and transferring analytical and computational skills for engineering design is an important portion of the engineering curriculum (McKenna, 2012). Recognizing this, some studies have focused on discussing how computer aided design (CAD) and modeling can be taught and used to guide engineering design learning. Carberry & McKenna (2014) explored students' conceptions of modeling and modeling uses in engineering design, finding that explicit teaching of modeling through modules in design education enhances students understanding and use of modeling in design. Similarly, Dixon & Johnson (2011) compared how experts and novices used mental representations in engineering design. Data was collected using verbal protocol analysis and structured interviews of both engineering junior/senior-level students and practicing engineers. The authors found three major conclusions: 1) the use of mental representations (i.e. propositions, metaphors, analogies) is important to engineering design; 2) experts, as compared to students, rarely used propositions or analogies in their problem space; and 3) experts differ from students in the ways they use within-domain analogies, between-domain analogies, heuristics, and formulas. Students tended to spend more time on problem identification than on problem solving, as well as used heuristics more than formulas, whereas experts used them equally.

Recognizing that students need assistance to think strategically when using modeling in engineering design, Toto et al. (2014) employed three different instructional approaches on first-year engineering design students' "strategic thinking" while using modeling software. The three instructional strategies included tutorial-focused instruction, object-focused instruction, and instructor led instruction. The study found that all students had similar previous experiences prior to any instruction, and student confidence in their ability to create a CAD object was similar. Students from the instructor lead section reported significantly higher confidence, but did not demonstrate significantly higher performance. Rather, they performed significantly lower than the object-focused section. Object focused instruction effected students' "declarative command knowledge, i.e. the ability to recognize, identify, and state the steps necessary to create the assigned object" and strategic use of software, whereas the tutorial-focused instruction effected students' "procedural command knowledge, i.e. the ability to group or chunk individual steps into a series of larger steps or procedures" (p. 28). The authors recommend that no one instructional strategy is clearly more effective, but rather should all be used at strategic points of instruction throughout a course (p. 32).

3.5 Conclusion

The purpose of this review was to identify and characterize the current state of engineering design education at the undergraduate level at large engineering programs in the United States. The following sections discuss how current literatures, as well as identified gaps in the literature, help identify implications for both practice and research of engineering design education.

3.5.1 Implications For Practice

From traditional engineering design education we can infer a number of implications. The apparent consensus of studies on first-year engineering design-based courses is that the ABET learning criteria, particularly those pertaining to "soft-engineering skills" (I.e. Creativity, communication, ethics, teamwork, global engineering, sustainability), are effectively accomplished through design-based courses (Barr, 2000; Ropers-Huilman et al., 2005, Lau, 2007; Moore-Russo et al, 2013). Additionally, design-based courses demonstrate improved retention rates and student engagement (Terpenny et al., 2008; Williams et al, 2010; Dalrymple et al., 2013; Kremer et al., 2013). Similarly, project-based capstone experiences have long been used as an approach to include engineering design learning in various engineering programs. Over time, a variety of approaches to capstone have been effectively implemented, mitigating some of the common issues that tend to arise in capstone courses such as faculty involvement, limited resources, and project management (Dutson et al., 1997; Bannerot et al., 2010). For example, graduate student coaches were used for a junior-level capstone design course, offering the opportunity for more individualized attention and frequent feedback for the undergraduate students (Manuel et al., 2008). Another increasingly common strategy towards capstone design is to offer students industry-sponsored projects, allowing students to be exposed to authentic engineering challenges and to gain experience in handling stakeholder constraints, project management, and preparation for entrepreneurship/engineering integration projects (Al-Rizzo et al., 2010; Norback et al., 2014).

Considering the literature discussing nontraditional approaches to engineering design learning, the most meaningful implication is that engineering design can be effectively learned in less traditional educational settings. For example, spaces designed specifically for design education learning have been very successful in terms of motivating students to be self-directed learners (Evans et al., 2007), exposing students to “realistic design” experiences (Coyle et al., 2005), and supporting student innovation and interdisciplinary experiences (McKenna et al., 2007). However, designed spaces can be costly and are often restricted to small-scale access (Coyle et al., 2005). Nontraditional approaches to engineering design learning that can be translated at a larger scale include virtual learning environments, such as the 3D multi-user virtual environment to teach aerospace engineering design described by Okutsu et al. (2013). Okutsu and his colleagues found that virtual laboratories did not affect student performance (positively or negatively) when compared to traditional pedagogies, however, virtual laboratories afford broader access (Harmon et al., 2002; Finger et al., 2007; Butler, 2009; Okutsu et al., 2013). Virtual engineering design experiences can be used to give large groups of students realistic engineering design experiences while requiring less space and resources. However, these virtual laboratories require time and resources to be spent upfront by developers and instructors, and tend to be considered time consuming by student users (Harmon et al., 2002).

In addition to engineering education literature that describes various experiences and interventions there is a body of literature that offers implications to practice based on research specifically on engineering design learning. For example, Hotaling et al. (2012) hypothesized that “students who take a multidisciplinary capstone design course have better outcomes than mono disciplinary capstone students as measured by job placement and/or independent evaluation by industrial professionals of students’ products” (p.631). Through a quantitative study testing that hypothesis, Hotaling et al. Confirmed their hypothesis, also finding that biomedical engineering students had the significantly highest odds of employment if they were in a multidisciplinary team (p.648). Other studies have indicated the significantly positive outcomes when students experience multi- or interdisciplinary engineering design experiences at the undergraduate level (Muske et al., 2006; Terpenny et al., 2007; McNair et al., 2008; BanneRot et al., 2010).

Product archaeology, which can be related to reverse engineering, has been another intervention in engineering design learning that has been discussed in engineering education literature, particularly for the purpose of teaching global, societal, economic, and environmental (GSEE) factors in engineering design (Neumeyer & McKenna, 2013). In general, various studies on using product archaeology as an approach to teaching engineering design have found that product archaeology positively impacts students' problem solving skills, professional skills (Moore-Russo et al., 2013), students' perceptions of their learning outcomes (Kremer et al., 2013), and knowledge transfer skills (Dalrymple et al., 2013). Students who work on human-centered design projects also tend to have better grasp of GSEE factors in engineering design (Neumeyer & McKenna, 2013). Although effective, product archaeology activities that involve common products can encourage design fixation, or the adherence to existing examples (Toh et al., 2013, p. 2).

Studies on the design and/or ideation process offer some insight into how students approach design problems. Atman et al. (2007) investigated novice and experts, specifically comparing the engineering design process of the two groups, finding that experts spent significantly more time on a design task than engineering students, experts used significantly more information gathering, and that experts considered significantly more objects during the design process. Other studies have discussed similar findings (Atman et al., 2008; Bailey, 2008; Cardella et al., 2008). To teach students better engineering design practices, reflective ideations activities and design heuristics have been effectively used to help guide students towards more expert-like behaviors (Magee & Frey, 2007; Ohland & Summers, 2007; Currano & Steinert, 2012; Daly et al., 2012; McNair et al., 2012).

Overall, it appears as though no one approach to teaching engineering design should be considered above all others, but rather a balance of traditional and nontraditional approaches can be appropriate in large undergraduate engineering programs. More traditional approaches, such as project-based cornerstone courses, are easily implementable as effective environments to introduce and deliver essential concepts pertaining to engineering design (e.g. communication skills, global/societal/environmental/economic factors, modeling techniques). However, more traditional approaches are restricted by time and space boundaries that nontraditional approaches are not hindered by. Nontraditional approaches allow engineering design experiences to be more consistent and long-term, and can be used to broaden student participation, while still effectively teaching students about teamwork, leadership, and the design process by offering student an opportunity to transfer their academic knowledge to authentic design challenges. Nontraditional approaches tend to involve more upfront costs, planning, and recruitment issues not typically seen with traditional learning approaches. Large research-driven universities should take advantage of the many available resources to offer students a balance of both traditional and nontraditional engineering design learning opportunities. The earlier, and more consistently students are exposed to engineering design, the better the outcomes (Newstetter, 1998; Jamieson & Lohmann, 2009; Atman et al., 2014).

3.5.2 Implications for Research

Literature on engineering design learning in engineering education also has important implications for research on engineering design learning, such as the studies done by Lawanto et al. (2013) that provide insight towards metacognitive and self-regulated learning strategies of engineering students during design projects. By specifically focusing on metacognition and self-regulated learning in engineering design learning, Lawanto et al. were able to characterize the various learning and designing behaviors that engineering students exhibited during a design task, finding that engineering students, regardless of academic performance, tend to focus on monitoring strategies over planning or cognitive strategies. Other related studies have found similar findings regarding engineering students' metacognitive behaviors (McCord & Matusovich, 2013; McCord, 2014)

Other research on engineering design learning includes literature on the use of computer-aided design (CAD) and other modeling strategies to facilitate engineering design education. For example, Dixon & Johnson (2011) compared students' and professional engineers' mental representations (i.e. propositions, metaphors, analogies) while solving engineering design problems, finding that experts, as compared to students, rarely used propositions or analogies in their problem space, and that experts differ from students in the ways they use within-domain analogies, between-domain analogies, heuristics, and formulas. Similarly, Carberry & McKenna (2012) studied the role of analytical, computational, and modeling abilities in innovation, particularly students' conceptions of the role of modeling in engineering design. Carberry & McKenna found that students do appropriate the language of the design community when describing models, however students rarely considered more abstract models (i.e. Mathematical, theoretical), implying that students tend to only consider tangible models or artifacts as useful models in design. Following this study, Carberry & McKenna (2014) also studied the use of modeling to teach students about modeling in engineering design, finding that explicit teaching of modeling through modules in design education enhances students' understanding and use of modeling in design (Carberry & McKenna, 2014; Toto et al., 2014).

Although existing literature has provided valuable insight towards research focus, design, and methodologies, there are still large gaps in the engineering design learning literature. First, there is a large gap in replicative studies that can help determine consistency and validation for existing engineering design education research (Atman et al., 2014). Additionally, revisiting the engineering learning sites taxonomy by Dorie et al. (2012), of the 8 common learning environments listed earlier, only half (curricular learning, extracurricular learning, service learning, and professional learning) have been represented to some extent by engineering design literature. Engineering education research on learning in designed settings, outreach learning, learning media, or everyday learning are much less commonly included in engineering education literature. As Dorie et al. (2012) have shown, all 8 of the common learning environments are valuable educational opportunities that most engineering students experience at one time or another. Research on other education contexts, such as science education and K-12 education has contributed some insight into possible approaches to studying more complex informal learning environments (Gerber, 1996; Brody et al., 2007; Allen et al., 2008; Bell et al., 2009; Ito et al., 2010). Education research can be challenging due to its nature of being human-centered research, and engineering students are no exception. Engineering students each have unique prior experiences that inform and influence their approaches to learning, conceptual understanding, and worldviews (Baxter-Magolda, 2001, 2004; Stevens et al., 2008). In order to better understand our students in a holistic way, engineering education research needs to consider the various common educational contexts where engineering learning occurs (Johri & Olds, 2011).

CHAPTER 4: SELF-DIRECTED STUDENT EXPERIENCES IN EXTRACURRICULAR ENGINEERING ENVIRONMENTS

4.1 ABSTRACT

Background Extracurricular engineering environments are a prominent part of many engineering students' educational experiences. Previous studies have found that participating in extracurricular activities positively influences student learning, however there is limited research that characterizes the value of these experiences for student learning of extracurricular engineering opportunities.

Purpose Our purpose was to investigate students' experiences in extracurricular engineering environments using a self-directed learning lens, with the goal of characterizing the affordances and barriers of these environments for learning and professional development.

Design/Method We used ethnographically-informed methods, specifically conducting naturalistic observations and focus groups with participating students, and collecting relevant archival data. We used a self-directed learner autonomy framework informed by Candy and Littlewood to guide qualitative analysis of the collected data.

Results Students participating in extracurricular engineering environments exhibited strong attributes of self-directed learners, particularly a willingness and ability to be challenged and to learn. The educational environments of the extracurricular opportunities cultivated these self-directed learning attributes by providing students a space to be exposed to an engineering community, authentic engineering work, and accessible resources. Findings from this study have several implications regarding the fundamental affordances of extracurricular environments that most influence students' experiences.

Conclusion By providing a space for students to express their engineering selves in primarily

self-directed ways, students have the opportunity to develop as even stronger self-directed learners, which in turn helps students develop a strong sense of self-efficacy in engineering. Also, the community and peer network that students inherently join by participating in extracurricular engineering environments further facilitates individual students' validation of their perceived experiences.

4.2 INTRODUCTION

Recent studies have demonstrated that vast amount of human learning experiences that occur in informal learning environments, as compared to formal academic learning (Bransford, 2007; Stevens et al., 2008; Feder et al., 2009; Ito et al., 2010). In order to comprehensively understand the educational experiences of engineering students, it is critical to look holistically at students' learning experiences. Traditionally, studies of engineering learning have paid disproportionate attention to formal learning experiences of students – primarily their classroom and/or laboratory experience. What have received considerable less attention are students' informal or extracurricular experiences and their role in engineering education. A better understanding of the multitude of ways in which students learning engineering is useful not only from a theoretical perspective but can also help guide curriculum and mentoring efforts. For instance, it is well documented that student persistence and retention is a critical concern across STEM disciplines and engineering in particular has been troubled by both migration of students out of engineering and an inability to attract students into engineering (Ohland et al., 2008). Previously studies have addressed this issue primarily at the institutional level (curriculum and instructional development), but recent studies take a more multidimensional view (Stevens, et al. 2008) emphasizing the standpoint of students. Students are now seen as more directly engaged in the design of their "pathways" or personalized learning trajectories and leverage "navigational flexibility” available to them (Baxter-Magolda, 2001, 2004; Stevens et al., 2008) often follow “unofficial routes”. Investigating these “unofficial routes” engineering students might take is vital in order to expand the understanding of the various contexts of engineering students’ learning experiences (Stevens et al, 2008) and to holistically account for their situated engineering learning (Johri & Olds, 2011).

In spite of the evidence for taking a broad view of personal trajectories of engineering students, engineering learning measures are still largely focused on assessing formal instructional outcomes. Traditional engineering teaching practices are designed primarily for providing “accountable disciplinary knowledge” or ADK to students (Stevens, et al. 2008) although being an engineer requires more than just mastering disciplinary knowledge. A recent approach toward improving engineering education has been to move emphasis away from theory-driven standardized education, characterized by traditional lecture-based pedagogies, and toward more design experiences, characterized by collaborative, creative, active, and informal learning approaches. The insight provided by engineering education literature is that non-curricular learning activities and extracurricular experiences should strive to enhance existing curricular opportunities, filling in academic gaps that traditional curricular activities do not have the time or resources to address, and should be considered within engineering education research as an influential factor when studying engineering programs (Lattuca & Litzinger, 2014). This is particularly pertinent in Research I universities in the United States, where undergraduate curricular experiences might be limited due to large class sizes, but where copious extracurricular design and research experiences might be available to students. It is known that extracurricular learning experiences have a significantly positive influence on students’ educational and professional development (Terenzini et al., 1996; Lattuca et al., 2006, 2011).

Closely investigating extracurricular experiences with a qualitative approach can help begin to identify explanations for the positive influences of extracurricular experiences.

The purpose of our study was to investigate undergraduate engineering students' experiences in extracurricular engineering environments using a self-directed learning lens, with the goal of characterizing the affordances and barriers of these environments. We used ethnographically-informed methods to investigate student experiences in extracurricular engineering environments, treating these environments as unique cultures within the engineering program of a large research-focused state university in southeast U.S. Specifically, we conducted field observations, focus groups and interviews with participating students, and collected relevant archival data.

4.3 Background and Theoretical Framework

4.3.1 Extracurricular Engineering Environments

Extracurricular engineering environments are possible learning sites where engineering students might experience less structured and more personalized learning opportunities within an engineering context. Such activities might also be referred to as non-curricular, co-curricular, or out-of-classroom activities, and are commonly used interchangeably in education literature. For the sake of consistency within this paper, and to remain consistent with the chosen vernacular of the study participants, extracurricular engineering environments will be used throughout this paper. Extracurricular engineering environments, for this study, specifically refers to any activity with educational intentions that is not an explicit requirement for engineering students to successfully complete an engineering degree.

Examples of extracurricular engineering environments include service-learning projects, undergraduate research experiences, design competitions, and professional learning experiences (such as internships and co-ops) (Dorie et al., 2012). Previous studies that employed mixed-methods approaches to gauge various influences on student outcomes, including extracurricular participation, have found generalizable evidence of the positively significant impact of extracurricular activities on engineering students' learning outcomes (Terenzini et al., 1996; Pascarella et al., 2005; Lattuca et al., 2006, 2011). Although these studies provide evidence-based generalizable claims about the contributions of extracurricular activities, there are remaining questions left unanswered. As mentioned earlier, it is clear that extracurricular experiences significantly and positively contribute to engineering students' learning outcomes, however, this does not provide a holistic understanding of engineering students' academic experiences with extracurricular activities (Strauss & Terenzini, 2005). The literature has also indicated that extracurricular experiences impact students' academic experiences and learning outcomes (Pascarella & Terenzini, 1991, 2005; Terenzini et al., 1999; Strauss & Terenzini, 2005; Kuh et al., 2008), yet there are remaining questions about which features and characteristics of extracurricular experiences are the most influential on students' academic experiences and learning outcomes (Strauss & Terenzini, 2005; Bransford et al., 2005; Lattuca et al., 2011).

A self-directed learning theoretical approach is a way to guide the investigation of extracurricular environments. After conducting a pilot of this study with an undergraduate automotive design team, using a grounded research approach, we found that one of the most salient characteristics of students' experiences was the amount of agency the students had over their work and their learning in that particular extracurricular environment. Students highly valued and took advantage of the opportunity to self-direct the pursuit personal goals and interests, and to be able to claim agency over their accomplishments (Authors, 2014). With the study described in this paper, we wanted to explore this emerging theme more closely by using self-directed learner autonomy as a guiding theoretical framework.

4.3.2 Self-Directed Learner Autonomy

Self-authorship, or an internally defined sense of self, is an important part of students' education and derives its power from three assumptions: 1) "knowledge is complex and socially constructed", 2) "self is central to knowledge construction", and 3) "authority and expertise are shared in the mutual construction of knowledge among peers" (Baxter-Magolda, 2001, p.188). Strong self-authorship is conducive to strong life-long learning abilities (Baxter-Magolda, 2004; King et al., 2009), an essential skill demanded of modern engineers (NAE, 2005, p.55; Dutta et al., 2012). Pedagogies that foster mutual construction of knowledge have been recommended to promote self-authorship, and such educational opportunities are often found in non-curricular learning sites (Baxter-Magolda, 2001, p.328). Using the self-directed learner autonomy framework as a lens to investigate non-curricular learning sites can help identify the features that foster self-authorship. Self-directed learner autonomy framework is a framework informed by Candy's (1991) self-directed learning theory and Littlewood's (1996) learner autonomy theory, which will be discussed in more detail in the following sections.

Self-Directed Learning**.** Self-directed learning is a broad theory, with many domains relevant to adult education research. As Candy (1991) discusses, self-direction as a term signifies a number of distinct meanings, particularly when self-direction is being differentiated between self-direct as a process of learning and self-direction as an outcome of learning. The four distinct domains identified by Candy (1991) include:

> *"…"self-direction" as a personal attribute (personal autonomy); "self-direction" as the willingness and capacity to conduct one's own education (self-management); "self-*

direction" as a mode of organizing instruction in formal settings (learner-control); and "self-direction" as the individual, noninstitutional pursuit of learning opportunities in the 'natural social setting" (autodidaxy)." (p. 23)

Specifically for this study, self-directed learning from the autodidaxy domain, i.e. "intentional self-education" (p. 158), has implications towards students pursuing co-curricular activities that are worth exploring. Tough (1979) first operationalized the concept of autodidaxy when he described "learning projects", which are collaborative settings where individuals intentionally seek knowledge or skills. This model of "learning projects" closely aligns with the types of non-curricular learning environments investigated for this study. Candy (1991, p. 199) describes five generalizations of autodidaxy that further demonstrate its implications towards non-curricular learning experiences:

1. Learning experiences are rarely entirely self-directed learning, but rather occur along a spectrum dependent on individual motivations and interests.
2. Learning experiences and/or outcomes viewed through a self-directed lens can rarely be anticipated or predicted; "accident or serendipity plays an important role".
3. Autodidactic opportunities most commonly emerge from unresolved programs.
4. Learners exhibiting autodidaxy are not aware of their role as learners. As Thomas (1967) explains, "It is the collective goal that is important, not individual enhancement, and thus the learning is merely a means to a collective end." (as cited in Candy, 1991, p. 197)
5. "Self-direct learning is rarely completely solitary. It often occurs in the context of a social grouping…"

Candy's (1991) framework of self-directed learning has implications for how to promote, as well as how to research self-direct learning. Specifically for engineering education contexts, studies have sought out to measure self-direct learning readiness (Litzinger et al., 2005), as well as pedagogical approaches to promoting self-direct learning (Felder & Brent, 2003). With regard to researching self-direct learning, Candy (1991, p. 459 - 466) provides a "profile of the autonomous learner". Additionally, Candy (1991) suggests research methodologies for investigating self-directed learning; primarily qualitative and naturalistic research methodologies that can provide "rich and varied experiences of individual self-directed learners" (p. 452). While there are important implications and suggestions from Candy's (1991) self-direct learning theory, a more finely defined framework of the autonomous learner phenomenon can provide a more specific investigation of students in non-curricular learning sites.

Learner Autonomy. The accepted definition of learner autonomy in education literature is the ability to "take charge in one's own learning" (Holec, 1981, p.3). In other words, students are empowered to have agency over what they want to learn and how they are going to learn. This is an important skill for students to have, particularly engineering students in higher education, since lifelong learning is one of the top skills expected of engineering graduates. An autonomous learner will be capable to "apply their knowledge and skills outside the immediate context of learning" (Little & Dam, 1998, p.1). More so, current and future job markets is increasingly becoming a dynamic and rapidly changing landscape, requiring engineering graduates to be more adaptable than ever (NAE, 2005).

Stemming from language education (Holec, 1979; Little & Dam, 1998), the theory of learner autonomy has been shown to have implications in other educational contexts (Benson, 1996; Yen & Liu, 2009), including engineering education (Bramhall et al., 2008). Although learner autonomy has been shown to be a positive predictor of academic achievement (Yen & Liu, 2009), this is most effective when students are provided sufficient guidance through advising or mentoring (Tinto, 1993; Benson, 1996; Bramhall et al., 2008; Yen & Liu, 2009). Such conditions (i.e. students taking control of their learning under the guidance of a mentor and/or advisor) can often be found in non-curricular learning sites.

Littlewood's (1996) model of learner autonomy has implications for students participating in non-curricular learning sites. The primary components of the learner autonomy framework are a "willingness and ability" to learn, where willingness derives from a learner's "motivation and confidence", and ability derives from a learner's "knowledge and skills". As described by Littlewood, each of these components of autonomy must be present in order to truly demonstrate learner autonomy:

> *"Thus, a person may have the ability to make independent choices but feel no willingness to do so (e.g. because such behaviour is not perceived as appropriate to his or her role in a particular situation). Conversely, a person may be willing to exercise independent choices but not have the necessary ability to do so…a person may feel highly motivated to learn outside class but lack the necessary knowledge or skills to organise his or her time effectively; a person may have ample opportunities to develop knowledge and skills for organising learning, but not wish to do so because he or she sees this as the teacher's role…" (p. 428)*

Originally proposed within the context of language learning, Littlewood developed a framework for developing autonomy with three domains (Figure 4.1): 1) autonomy as a communicator, 2) autonomy as a learner, and 3) autonomy as a person (p. 431). Across each domain, Littlewood discusses ways in which learner autonomy can be developed. For instance looking at the "independent work" area, Littlewood suggests that students' "willingness and ability to engage in self-directed work" should be encouraged (p. 433). Similarly, for "communication strategies", Littlewood suggests an approach to "develop students' willingness and ability to focus on communication rather than accuracy" (p. 433). Considering "learning strategies", "expression of personal meanings", and "creation of personal learning contexts", Littlewood again suggests increasing students' willingness and ability to engage in self-directed work by personalizing the content to each students' personal interests.

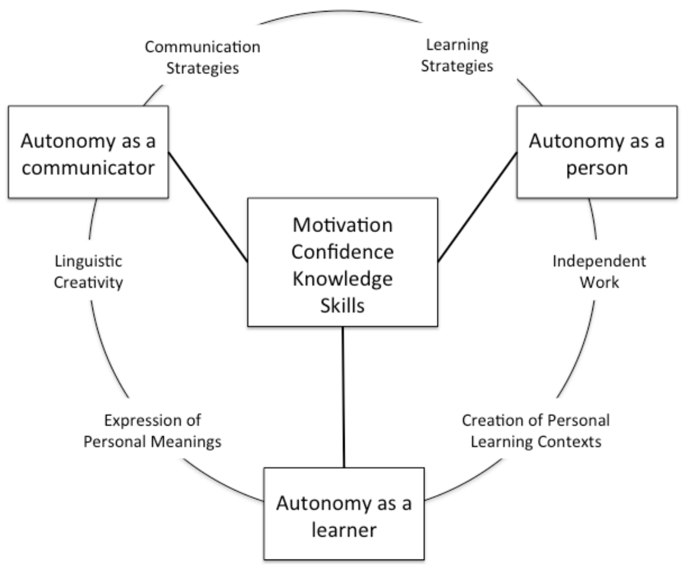

Figure 4.1. Framework for developing learner autonomy, adapted from Littlewood (1996, p. 432)

Finally, through "linguistic creativity", Littlewood is referring to a student's ability to creatively use the content/skill learned in creative ways and situations. Although Littlewood's framework for developing learner autonomy is presented for the context of language learning, it can also have applications to engineering education. For example, engineering educators should strive to increase engineering students' willingness and ability to engage in self-directed work, through personalized experiences, and engineering students should be just as able to apply their skills in creative ways and contexts as linguistics students (NAE, 2005; Dutta et al., 2012).

SELF-DIRECTED LEARNER AUTONOMY. Self-direct learner autonomy merges pieces of the two frameworks previously described, as shown in Figure 4.2. Candy's self-directed learning theory provides the initial lens of "intentional self-education", as well as a profile of the self-directed learner that is worth investigating. Littlewood's learner autonomy framework provides a specific framework with well-defined domains that can help inform and conceptualize rich qualitative data.

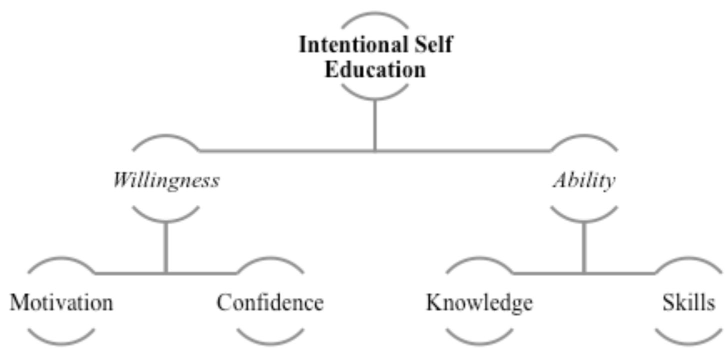

Figure 4.2. Self-Directed Learner Autonomy framework informed by Candy (1991) and Littlewood (1996).

On the job training programs are becoming more prevalent, and it is becoming more common for students to find job opportunities in areas that do not yet exist, requiring them to have skills that are not yet known or needed (NAE, 2005; Dutta et al, 2012). Students with well-developed and practiced self-directed learner autonomy can ideally demonstrate the necessary lifelong learning skills needed to succeed in a modern world. It has been shown that current engineering students demonstrate only average self-directed learning skills (Litzinger et al., 2005), however we believe the most rich self-directed learning experiences, which are seldom investigated, are learning opportunities that students engage in outside of the classroom.

4.4 Research Design

4.4.1 Research Goal

The purpose of this study was to investigate students' experiences in extracurricular engineering environments using a self-directed learning lens. Since our primary goal was to understand student experiences within a situated context, qualitative methods that provide rich descriptions are appropriate (Creswell, 2008; Johri & Olds, 2011; Johri et al., 2014). We used ethnographically-informed methods to investigate student experiences in extracurricular engineering environments, treating these environments as unique cultures within the engineering program of a large research-focused state university in southeast U.S (Baillie & Douglas, 2014). Specifically, we conducted field observations, focus groups and interviews with participating students, and collected relevant archival data. We used a self-directed learner autonomy framework informed by Candy and Littlewood, which informed data collection protocols, provided *a priori* codes, and guided the qualitative analysis. Using a self-directed learner autonomy framework allowed us to more closely characterize the particular affordances of extracurricular engineering environments that uniquely influence student learning and experiences.

4.4.2 Ethnographic Methodology

Traditional ethnographic methods stem from anthropology, where researchers study and observe a select group of people and their natural behaviors as they go throughout their daily life (Case & Light, 2014). The ethnographer is concerned about understanding and describing how a group of people "live, how they talk and behave, and what captivates and distresses them." (Emerson, 2001, p. 1) When conducting an ethnographic study, the researcher is not really studying a group of people, but rather learning from a group of people about how they perceive an experience or phenomenon (Spradley, 1979; Glesne & Peshkin, 1992). Coming from an interpretivist epistemology, our purpose is to understand and situate descriptions of student experiences in extracurricular engineering environments (Johri, 2014). Our goal is to provide rich descriptions students' perceptions of their experiences, looking to understand a situated experience rather than to generalize an outcome to a larger engineering education context. Therefore, adopting ethnographic methods appropriately aligns with our research purpose (Borrego et al., 2009; Creswell, 2009). Traditional ethnography presupposes a long involvement with a research site and subjects which was not within the scope of the current work. Therefore, we adopted methods from ethnography with some modifications and have termed our approach ethnographically-informed.

The specific research sites that we investigated were five distinct extracurricular environments where students were working on engineering-specific tasks and goals. All groups were extracurricular groups, which is defined as educational groups in which students participated completely voluntarily. All student groups were from a single large research-focused state university in southeast U.S., however one of the research sites included students from various engineering programs in the U.S. (as will be discussed in more detail later). We chose the five research sites because our research goal was to investigate non-curricular educational experiences for engineering students from an R1 institution in the U.S., to bring to light what occurs outside of the engineering classroom, and to consider how these non-curricular activities are influencing engineering students (Bransford, 2007; Stevens et al., 2008; Johri & Olds, 2011).

4.4.3 Research Participants

The five research sites, and the number of research participants from each site are detailed in Table 4.1. Of the five research sites, four explicitly emphasized exposing students to engineering design, and all five were non-curricular (i.e. not a degree requirement, student participation completely voluntary). However, junior and senior-level students from the ADT, depending on the students' specific engineering discipline, were permitted to receive independent study or senior design credits for their contributions to the team.

Table 4.1. Study Research Sites

Extracurricular Environment	Description	Context	Study Participants
Automotive Design Team (ADT)	Team of undergraduate students working toward annual automotive design competitions	Common working space provided by university; Industry and academic sponsorship; One faculty advisor	6 students from multiple cohorts (Total ADT members: ~100)
Electrical Engineering Prototyping Laboratory (EEPL)	Groups of students working on various and unique self-defined engineering design projects	Common working space provided by university; Academic sponsorship granted based on student proposals; One faculty advisor	4 students from one group (Total EEPL members: ~50)
Global Service Learning Project (GSLP)	Team of students working toward a global service project to design, implement, and evaluate sustainable power sources for a rural school in a third-world country	No common working space provided by university; Weekly meetings held in available classroom on campus; Industry and non-profit sponsorship granted on student proposals; No faculty advisor, but one industry mentor	8 students from various cohorts (Total GSLP members: 8)
Additive Manufacturing Competition (AMC)	Teams of students working through a 10-week additive manufacturing design competition	No common working space provided by university (students chose a workspace based on convenience and availability); Industry and academic sponsorship; Two faculty advisors	18 students from multiple teams (Total AMC members: ~50)
Biomedical Engineering Undergraduate Research (BME-UR)	Group of students accepted into a biomechanics-specific undergraduate research experience	Various research labs on university campus; NSF funded; One faculty advisor per student	11 students working in various biomechanics labs within the university; students from various engineering programs in U.S. (Total BME-UR member: 11)

Students from all five research sites worked on primarily student-run projects. Students from the EEPL were provided peer mentors, who were typically more experienced undergraduate students, to provide team leadership and guidance. Students from the GSLP and the AMC had undergraduate student leadership, typically a student who was chosen by the student team or who organically rose to the occasion. The ADT regularly met with a faculty advisor, but were still very student-run, with a head undergraduate team leader who oversaw up to 10 undergraduate sub-team leaders who then oversaw the sub-team members. The BME-UR students worked the most closely with a faculty advisor, with each student being assigned a specific faculty advisor, similar to a typical graduate school advisor-advisee structure. Students in all five research sites came from various engineering disciplines, and represented all stages of an engineering undergraduate career. With the exception of the BME-UR, there were also a handful of non-engineering students (business, physics, math, and industrial design) participating in the other four research sites. Students from the BME-UR were not from the university that offered the BME-UR, and came from a diverse set of engineering programs in the U.S.

4.4.4 Data Collection

Adopting ethnographically-inspired methods, data collection involved conducting field observations, focus group discussions and individual interviews, and collecting archival data (Spradley, 1979; Borrego et al., 2009; Creswell, 2009). Focus group discussions with participating students were done for each research site, as detailed in Table 4.2.

Table 4.2. Focus Group Discussions by Research Site

Organization	Focus Groups
ADT	45 min. focus group with 6 students
EEPL	50 min. focus group with 4 students
GSLP	50 min. focus group with 8 students
AMC	7 focus groups with 18 total participating students; (2 - 4 students per group; 30 mins - 1 hr)
BME-UR	1 hr Focus group with 6 students 1 hr Focus group with 4 students

The focus group protocol was informed by the self-directed learner autonomy framework, primarily focusing on any demonstrations of students' willingness and ability to learn in each specific situation. Focus groups were used to understand the collective student experience in each research site. The focus groups were semi-structured, lasted 30-60 minutes, and were audio-recorded. Overall, 46 students participated in focus group discussions, spread through 12 separate focus group sessions. Example questions and prompts during the focus group discussions were:

- What comes to your mind when you think of when you first joined [respective group] and what drove you to join [respective group]?
- Considering your goals when you first joined, and the expectations you had, have you met your personal goals, and has the [respective group] experience met your expectations?
- How would you compare your learning experience in [respective group] and your learning experience in a typical engineering class?

- What kinds of things have made participating in [respective group] easier for you?
- What kinds of things have made participating in [respective group] harder for you?
- What do you think has been the most meaningful part participating in [respective group]?

Field notes were collected during field observations of each research site; observations were typically during any student meetings, work sessions, symposiums, local competition events, or social events occurring throughout the course of the study, amounting to about 3-12 hours of observation per research site (Geer, 1964; Spradley, 1979). Field observations were used to inform focus group discussions, but also provided a rich set of data collected in real-time naturalistic settings, enhancing the focus group data. Archival data, which consisted of Facebook pages, official websites, resource management sites, proposals, and reports or other documentation, was also collected, primarily as a means for better understanding the contextual and cultural factors at play in the research sites. This rich set of data allowed us to investigate extracurricular engineering environments aggregately, but also comparatively, helping us identify and characterize the unique affordances and barriers of the research sites.

4.4.5 Data Analysis

Focus group data from all research sites were transcribed for analysis, and all field notes and focus group transcriptions were grouped together by research site. Although all data was aggregated for primary analysis of the affordances of extracurricular engineering environments in general, keeping the data grouped by research site allowed us to identify unique affordances and barriers for research site. Using a variety of data sources allowed us to triangulate our findings to ensure research validity (Leydens et al., 2004; Creswell, 2009).

All transcribed focus group data was coded using *a priori* codes informed by the self-directed learner autonomy framework previously described as shown by Table 4.3.

Table 4.3. ***A priori*** **codes, informed by self-directed learner autonomy (Candy, 1991; Littlewood, 1996)**

Category	Codes	Sub-Codes
Willingness	Motivation	Curiosity/openness
		Venturesome/creative
	Confidence	Reflective/self-aware
		Persistent/responsible
		Positive self-concept
		Self-sufficient/independent
Ability	Knowledge	Logical/analytical
		Information seeking/retrieval skills
		Knowledge about learning process
		Use criteria for evaluating
	Skills	Methodical/disciplined
		Flexible
		Interdependent/interpersonally competent

As previously mentioned, the self-directed learner autonomy framework was used to guide thematic coding based on preliminary findings from an earlier pilot study of the ADT (Authors, 2014). To maintain trustworthiness, two researchers performed data coding separately, and any discrepancies were negotiated. Also, individual reports discussing the findings for each research site were sent to pertinent members of each research site for member checking. A secondary coding of the focus group data was then performed to identify other emerging patterns within and among the five research sites. Triangulation between the focus group data, observation data, and archival data was conducted to further identify and validate emerging patterns outside of the *a priori* codes.

4.5 Findings

Investigating students' experiences in extracurricular engineering environments through a self-directed learner autonomy lens helped identify the way students exhibit self-directed learning attributes, but also revealed the characteristic affordances of extracurricular engineering environments that cultivate self-directed learning habits. By the mere fact that students are so wholeheartedly enthusiastic to be a part of any of the studied extracurricular engineering environments inherently indicates a strong willingness and ability to learn and to be challenged by the students.

Analysis of the collected data revealed the various ways in which students exhibit self-directed learner autonomy attributes, including a strong willingness to learn. It was evident from the data that students were highly intrinsically and extrinsically motivated to pursue the specific challenges presented in each of the extracurricular environments. Students also exhibited positive perceptions of their confidence to holistically accomplish their personal and collective goals, even during times when they felt intimidated or unsure of their ability to complete specific tasks. This willingness to learn appeared to be strongly influenced by community aspects of the extracurricular environments, which will later be discussed in more detail.

Students also exhibited strong abilities to learn, specifically considering the knowledge and skills required of the students to pursue and accomplish the various challenges. Most participating students in all research sites had substantial prior knowledge relevant to their specific challenges, however it was found that this could act as a barrier at times. Students with limited prior knowledge were also capable of catching up to their peers, and exhibited strong strategic resource seeking skills that clearly benefited their success. Students also demonstrated advanced and unique skill sets relevant to their specific challenges that were acquired as a result of the necessity for success, both technical and "soft" skills. Students' abilities to learn were also strongly influenced by community aspects of the extracurricular environments.

Two emergent findings not captured by the self-directed learner autonomy framework were the roles that community and self-efficacy play in self-directed learner autonomy. As stated earlier, community aspects of the extracurricular environments strongly influenced students' willingness and abilities to learn. Additionally, by having the opportunity to practice and exhibit their abilities beyond curricular expectations, students' self-efficacy development was also profoundly influenced. As such, it appears as though community and self-efficacy attributes act as inputs and outputs to the self-directed learner autonomy framework. The following sections provide examples of the ways students demonstrated self-directed learner autonomy attributes, as well as examples that further describe the roles that community and self-efficacy play.

4.5.1 Willingness to Learn

A common characteristic among students participating in any of the extracurricular engineering environments that was immediately evident was the innate passion students have towards what they do. As expected, many of the participating students joined their respective student group with a prior goal of becoming an engineering major in order to be able to work with their respective challenges, i.e. work with cars, help others, work on robotics, etc.

> "I mean since I was pretty young, my dad took me to the New York Auto Show and I kinda gotta really really interested in the whole automotive thing, and I got a subscription to Car & Driver that I read cover to cover every month. So, when I heard about this I really wanted to get involved, because of that, I wanted to work on the, I didn't really get a chance to work on them as a kid because we didn't have a garage or anything, but I wanted to work on [the ADT car], you know get my hands dirty with something like this." [ADT-S1]

> "So this seemed like a great way of, I'm very interested in alternative energy as well, it kind of seemed like a good way of doing the engineering, and the doing the volunteer work all at the same time." [GSLP-S1]

However, less expectedly, there were also students who stumbled upon their respective student groups, not really knowing what they were getting themselves into, but only knowing that they wanted to get authentic hands-on engineering experience. Among all students, there was an evident desire to be challenged and exposed to authentic engineering work.

> "I think learning new things, and, like stepping out of your comfort zone, because there's like a psychological resistance, but I think learning about new things, that would be the one most meaningful things for me." [AMC-S1]

> "I came in as undecided and somehow found my way into engineering, so I was just looking for a way to get my hands dirty try to feel out what engineering really was and so I found my way to ADT, and now it's the coolest thing ever." [ADT-S2]

> "I liked the learning part, and like the innovation – I thought that was cool. I like creative hands on stuff, that's my thing. So [working on project] and just thinking of it, the design part was super fun. Which you don't really get to do in classes, especially in [electrical engineering]." [EEPL-S1]

It was evident from the focus group and observational data that students were highly intrinsically and extrinsically motivated to pursue the specific challenges presented in each of the extracurricular environments. For the student groups that were provided common work spaces, there were rare moments in the day that those spaces were not occupied by participating students. And participating students were rarely observed as off-task; if they were there, they were there to work on their projects or related tasks. Students demonstrated high levels of motivation to learn all that was necessary to successfully accomplish their tasks, common goals, and personal goals. Students willingly took agency over what they learned, intentionally seeking every bit of knowledge or becoming proficient in specific skills if they believed it would help them succeed with their specific challenges. This willingness and hunger to learn expanded outside of the extracurricular environments, and went into the classes that students were taking.

> "For me it makes me think like what next...It makes me think differently about school in general, cause instead of thinking 'Oh this is going to be on the exam' it's 'Oh how can I use this on my next project?' It makes you think about your classes completely differently. Because instead of 'Oh this is on the exam and that's why I need to know it' - No. You need to know it because you get to use it. That's the coolest part [of the AMP Lab]." [EEPL-S2]

> "Once I joined [ADT], that's why I was so motivated to stay [in engineering], because I've been taking those classes, and I had no idea why I need to take those, why do I have to learn all this, and it just didn't make sense. And then it just like clicked that I need dynamics to do this and this, and then, I need fluids to do this and this, and then it just kind of combines... so I like that a lot about ADT, that like, the way the classes, like come together, you're not just studying and doing problems." [ADT-S3]

> "…I feel like I'm definitely more prepared for those kinds of classes [design/research project courses]." [BME-UR-S1]

Students also exhibited the necessary confidence to pursue their collective and individual goals. Although, initially students might be overwhelmed and intimidated by a lack of experience, the environment that the extracurricular groups provide helps students to quickly gain and develop the confidence needed to succeed with their challenges, and more importantly, the confidence to identify as engineers.

> "I definitely think that engineering to me isn't a career path, it's like almost a way of life, you know, it really influences a lot of things and the person that you are. Being a part of [GSLP] really helped bring that side of engineering out for me, that I'm not just, it's not just what I do, it's who I am. So that's one thing that I really enjoyed taking away from [GSLP]." [GSLP-S2]

> "I've never been a part of a project from start to finish...just seeing the research process...just taking the time to think through all that, I really like that full process. I know more about the project as a whole which is nice, and I feel more prepared for something like grad school." [BME-UR-S2]

> “[The AMC was] definitely a steep learning curve, but the exposure is great. It’s great just stepping into this world and getting to try out all these new things” [AMC-S2]

4.5.2 Ability to Learn

The extracurricular engineering environments also afforded students the opportunity to express and discover their abilities to learn. The students demonstrated high levels of self-awareness, recognizing the gaps in their knowledge, skills, and experience, and intentionally looking for ways to fill those gaps. Having that level of exposure, and rapidly learning how to learn, students were then capable of success with their respective challenges, as well as with their engineering curriculum.

> “It was that you had to know how to do these things in order to get to the end product that you desire. And that was a enough motivation for me to learn it... I would say personally I ended up learning a lot about the other software packages. My cad skills, they were good in one area before, but now they’re more rounded than they were before.” [AMC-S3]

> “For me the [EEPL] is a place where I’ve learned a lot more out of it, and how to do things properly, whereas before it’s just kind of figuring it out on your own, seeing what works and what doesn’t.” [EEPL-S3]

> “[GSLP] has that cultural component that you’re not going to get you know sitting here and doing this design work and you’re not going to get, you know, in a classroom.” [GSLP-S3]

During observations, first impressions of the student members in each extracurricular environment was that they were confident and capable engineering students, if not evident by their recent successes in previous competitions and symposiums, but by the way the students competently and skillfully functioned and behaved in their environments, or by the way they clearly articulated progress during student meetings. However, even the students admit that they do not always have it all figured out, and they are okay with that.

> "…even professionals never really know what the heck they're doing. So, that's where we're kinda, where you gain the confidence and… the raw knowledge or raw resources that we already have; you gain it in the passion and the drive the team members have, and then develop the new [members] as they come through the program to tackle new fronts…we always recruit a good batch of folks, and the ones that stick around for the long haul are always ready to take on [new] things." [ADT-S4]

> "We had no idea how to do anything. As first semester sophomores, we still didn't know anything. So we went in and actually learned a lot, it was more like a walk through project – not like on your own, we joined [an existing project], so it was mostly done...I joined, and it was kind of intimidating because everyone seems to know what they're doing, but then you're there a little longer, and you figure out no one knows what they're doing, everyone is kind of learning as they go. And then you learn how to learn, so that's cool." [EEPL-S4]

What makes these groups of students successful despite their knowledge gaps, is their capability to unabashedly acknowledge their weaknesses, and focus on developing those weaknesses and enhancing their strengths, all for the greater good of the team. All being a "hands-on, minds-on" type of environments, the extracurricular environments inherently become spaces for skill realization and development, particularly with respect to skill transfer. Students demonstrated competency in curating their knowledge, skills, and prior experiences in ways that helps them achieve their goals for their respective challenges, as well as to achieve their own personal goals.

> "The goal is to really just consistently win in some fashion on many fronts. Winning is not just finishing first. It's also have a great education on the team, establishing a legacy." [ADT-S5]

> "And that's where our team experience previously definitely helped us. Because we knew most of these limitations, we knew what we could design and we knew what we couldn't' design from previous experience with additive manufacturing" [AMC-S4]

> "This has been like a confidence booster for me, I feel much more confident in my ability that if I'm given something, even if I don't know how to do it, I could totally figure out, because I've had to do that multiple times throughout the weeks here." [BME-UR-S3]

In general, the extracurricular environments gave students metacognitive opportunities to realize their strengths and weaknesses in regards to their knowledge and skills. They applied what they knew as much as possible, and when they found their specific skills or knowledge base were insufficient they quickly sought out the necessary resources to build on their previous knowledge and skills. The driving force behind students' pursuit of knowledge and skill development was strongly influenced by a drive to succeed, to reach their fullest potential.

> "I think inherently as a project it's more seeking success rather than avoiding failure. If you mess up terribly in this competition, you don't lose anything other than the time you put into it." [AMC-S5]

> "It's kind of intimidating to always work with [principal investigator] just because you don't want to ask a stupid question because I feel like it's a constant interview. I want to be as professional or as impressive as I can be." [BME-UR-S4]

> "Yeah, there's a big difference, between seeing like, 'Oh I got this really good grade on a test', that they told us what we had to do and I studied for it. There's a difference between that and then seeing like this circuit that you built...It's a really big sense of accomplishment, that your work is actually getting something accomplished, and getting something made, rather than a grade on a report card." [EEPL-S1]

> "It forces you to push yourself. In a class you get to what you need to do, and you might add a little bit more, and then you're done. In this, you work on something, you see you know do I like where this is, or can I add more?" [EEPL-S2]

4.5.3 Community Aspects

One of the most influential characteristics of the extracurricular environments that fosters students' willingness and abilities to learn are the strong community aspects of the environments. Participating students depend on one another, technically and emotionally, to succeed as a team, but also to succeed as individual engineers. This is something that the students recognize and take very seriously.

> "I think probably my best friends from college have come from [ADT] ,and I know I feel maybe responsible…to the rest of my team, to provide and perform, because I want us to do well and I want myself to do well, and I want everyone else around me to do well. And I feel that responsibility, and that drives me personally." [ADT-S6]

> "I like the fact that people know what they're doing, because I don't. this is kind of, this is the first thing like this that I've ever done. And it's like if you just happen to be sitting next to someone,and you have a problem, they're all going to help you. They're all really friendly. If they have experience with whatever issue you're working on, they're very apt to kind of help you out." [EEPL-S3]

> "I think it's nice that a lot of us, we have different backgrounds but we can relate on a lot of things...there's a lot of consoling going on in the dorm." [BME-UR-S5]

The sense of community that these environments provide students is one of the most influential affordances of extracurricular environments, one that might have been more difficult to find had these students not had the opportunity to participate. By finding a group of likeminded peers, with similar goals and interests, yet diverse backgrounds and unique approaches to thinking, students are able to learn more broadly and richly about engineering within a situated context.

> "It's been extremely positive because I do cell-work all day, but I have no idea if that's what I want to do for the rest of my life, and so it was cool even in social situations, back at the dorm after the day, still kinda learning about another aspect of [biomechanics] that could be interesting. Cause I think what everyone is doing is really interesting! Without talking to other people…I wouldn't experience anything but cells, which would be unfortunate." [BME-UR-S6]

> "You also learn a lot about yourself, how you work best, and how you work on projects best. This project in particular, I learned a lot about how you should go about doing projects, how I work in groups. In class projects they kind of rush you through it, they force you to do it a certain way, and it's very limiting and it kind of kills your creativity." [EEPL-S4]

Having a community among peers is not the only community aspect identified in these environments; students were also cognizant of how their efforts had larger social impacts beyond their specific work. The students believed that the work they were doing impacted "the greater good"; either the greater good of their specific organization, or even a much more global greater good. Despite the most substantial barrier of extracurricular environments (which would be time, as indicated by students in all five research sites), the students still insist on participating in these environments, working through weekends and at all hours of the night. When asked about this behavior, students immediately pointed to the fundamental community aspects of the environments.

> "[I] definitely want to see the project like move forward and continue. I've dealt with other projects that come to a stand still for whatever reason…When you have a connection, when you've traveled, you want this to happen. You want people to have electricity, it's kind of, if you don't do it, then no one else will." [GSLP-S4]

> [ADT-S1] "I mean it's a labor of love"
> [ADT-S2] "You don't even think about it"
> [ADT-S3] "It's just part of your life now"
> [ADT-S1] "Yeah the day just goes by." [Exchange between 3 ADT students]

> "Especially when you go there everyday, you want them to see that you're doing well too. It's not really like sense of competition, it's like they see you everyday and they see you getting something done, it makes you feel better about yourself." [EEPL-S3]

4.5.4 Self-Efficacy Development

One of the most salient positive impacts of the extracurricular engineering environments was that it enhanced students' self-efficacy, or the perceived confidence in their abilities as engineers. Many of the participating students had little to no authentic experience with their respective challenges, and the few students who had relevant prior knowledge/experience admitted that their previous experiences were simplified and narrow. By participating in any of the extracurricular environments, students were exposed to questions, approaches, and tasks unlike anything that challenged the students beyond what they had previously experienced.

> "[ADT] was something that I kinda just never thought about, and it was definitely a challenge for me to learn something new." [ADT-S2]

> "A lot of my research I've done in the past has been cellular based…one of the things I wanted during the summer was to get more mechanics applied to it…I got to see the other sides of it too." [BME-UR-S4]

> "You also learn a lot as you go though, no matter what project it is, whether you're learning how to do something, learning about something new, or if you're learning process – you're learning a lot. You also learn a lot about yourself, how you work best, and how you work on projects best." [EEPL-S2]

Although initially intimidated and overwhelmed, the students noted that the challenges they came across were invaluable learning experiences that gave them the confidence to pursue future engineering ventures. This was often a positive consequence of having the unique opportunity to express agency over their learning and work. The students were very proud of the work that they could truly call their own, the work that had forced them to think more critically and creatively than anything that had previously encountered.

> "One of the other things for me personally, a lot of the projects that you get to work on in school they're all directed by a class and this was a chance to kind of make it completely self-directed and self-motivated, which was a huge driving factor for me. It just added a sense of ownership to the project that you wouldn't get in a normal class, which I found really really intriguing." [AMC-S6]

> "[BME-UR] gave me the opportunity to think about it and figure it out on my own... I very much feel like mine is my own project. The prompt was given to me, because they're going to be using it for something, but the guidance has been really limited, I appreciate that... I can sit back and be proud of it." [BME-UR-S7]

“My favorite part of the design process *hands down* is that moment when you shift from designing in a computer program to actually holding the thing you designed... [My design] actually exists. And that’s a beautiful part. And I love that part of the design process and I find it completely addicting.” [AMC-S7]

Students also attributed gained confidence to a other aspects of their respective environments, particularly the authenticity of the challenges. In general, having the opportunity to work on a truly authentic engineering research or design project, from beginning-to-end, culminating in an annual competition or symposium presentation, was one of the most crucial affordances of all five of the extracurricular environments. The opportunity to express and be exposed to their fullest potential was a substantially influential affordance of the extracurricular environments, one that cultivated the development of students’ self-efficacy as engineers.

“I’ve never been a part of a project from start to finish…just seeing the research process…just taking the time to think through all that, I really like that full process. I know more about the project as a whole which is nice, and I feel more prepared for something like grad school.” [BME-UR-S3]

“Here it’s actual hands on, like here’s a problem, you gotta assess it, you analyze it, and then you implement it all the way through, like beginning to end. That’s the best experience I’ll probably get in my entire time here is a volunteer thing.” [GSLP-S8]

“The most meaningful part, for me, is that [EEPL] has made me change my standards. Like before, [I would] go to class, learn some stuff, maybe study a little bit after, and ‘ok yeah I think I understand it’. But then [EEPL] raises the bar. Can you use it?” [EEPL-S1]

"You kind see different sides of how the world works. Both with team work, how to get things done how things don't get done failures and successes hand in hand, also how to bring package, something that is complex...I can really go through the *whole* process on my own and come out with a story to tell rather than just a grade.” [ADT-S8]

"The design projects that you do in [class], until senior design obviously, you don't actually build whatever you design...it's all just, you just design it on paper or computer, you never actually build a prototype, so it was cool to go through the whole design process and actually have something that works in the end." [AMC-S14]

4.6 Discussion

The findings presented earlier identified how engineering students in extracurricular engineering environments exhibit self-directed learner autonomy habits, as well as identified the affordances of extracurricular environments that encourage self-directed learner autonomy habits. The findings provide implications for how researchers might frame self-directed learner autonomy in the context of more informal learning environments. The study also has implications for practice, to enhance and minimize the affordances and barriers of extracurricular engineering environments. Lastly, we address the imitations and future directions of this work.

4.6.1 Self-Directed Learner Autonomy

As described in the previous discussion of the findings, community aspects of extracurricular engineering environments plays a substantially influential role on the success of these environments and their respective participating students. Each of the described environments affords students to have a space to come together as a community of like-minded individuals, with diverse skill sets and prior experiences, all working together to achieve a common goal (or in the case of the BME-UR, supporting each other to achieve similar goals). These environments cultivate students' development as self-directed learners, and allow students to achieve challenging goals without falling through the gaps of their individual knowledge or skill weaknesses (Wenger, 1999; Baxter-Magolda, 2009). In having such a rich experience, students' self-efficacy is positively influenced, further driving their self-directed learning habits. Figure 4.3 represents a visualization how self-directed learner autonomy is influenced and developed.

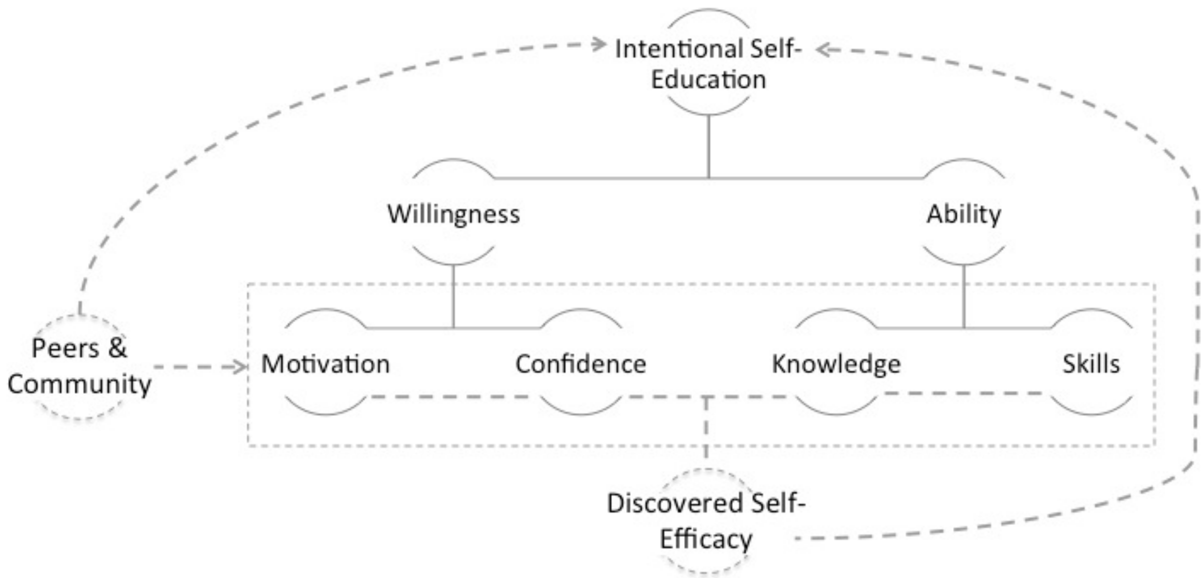

Figure 4.3. Self-Directed Autonomy in Extracurricular Engineering Environments Learner

These environments provide a safe space for students to interact closely with faculty that advise or sponsor these environments. The work that students do is primarily student-run, but students are still able to have the opportunity to get feedback or advice from faculty advisors, either through regularly scheduled meetings, office hours, or occasional emails and phone calls. The support from faculty is more than just for technical guidance, however. As briefly mentioned in the previous section, one of the biggest barriers of extracurricular engineering environments is the major time constraint that these environments impose. Students typically (and willingly) spend the majority of their limited time working on their respective challenges, which can put a strain on the curricular obligations students have. Receiving pushback from curricular and administrative demands can quickly become discouraging to students. Thus, students highly valued just knowing that they had general support from someone at the faculty-level - someone who encourages the students to pursue their goals, who guides through the failures and celebrates the successes.

Faculty advisors quickly step into mentorship roles, along with the students' more experienced peers, providing rich network of mentorship and community that helps students succeed in the classroom, and thrive outside of the classroom. As a result, these extracurricular environments become an accessible opportunity for students from large R1 institutions to find small, personalized educational experiences reminiscent of small-teaching schools. These environments provide spaces where students are not an anonymous student in a large class, but rather a recognizable individual who is part of a small community working towards achieving common or similar goals.

Findings also found that by having the opportunity to practice and express their knowledge and skills, and apply their knowledge and skills in authentic and supportive environments, students also experience strong self-efficacy development in extracurricular engineering environments. As such, self-efficacy development can be considered an "output" of self-directed learner autonomy experiences; i.e. as students experience successful self-directed opportunities, they are more confident in their engineering abilities. However, self-efficacy development can also be considered an "input" to self-directed learner autonomy; i.e. by gaining confidence in their engineering abilities, students continue to pursue other engineering challenges, further expressing self-directed learner autonomy behaviors. This implies that students' experiences in extracurricular engineering environments, which inherently encourage self-directed behaviors, enhance students' self-efficacy in authentic engineering contexts, which encourages students to further pursue self-directed opportunities and challenges.

4.6.2 Implications for Practice

Considering that extracurricular engineering environments can have such an influential impact on students' self-efficacy, this also implies that these negative student experiences in such environments could thus negatively impact students' self-efficacy and damper students' self-directed learning behaviors. As such, our findings have several implications for practice in order to enhance the affordances and minimize the barriers of extracurricular engineering environments.

It can be presumed that the participating students already contained attributes of strong self-directed learner autonomy (i.e. willingness and ability to learn) without intervention of the extracurricular engineering environments, however that can not be determined with the available data. What can be said is that the extracurricular engineering environments offered a unique and important opportunity for students to discover and showcase their agency over their learning experiences. This in turn has incomparable influences on students' professional identity, future goals, and future achievements (Eccles & Wigfield, 2002; Baxter-Magolda, 2009). By attempting and experiencing a challenging student-driven project from start-to-finish, students were forced to understand and navigate their strengths and weaknesses in order to succeed. The students were willing to challenge themselves in this way because to them their respective environments presented a space and an opportunity to have an authentic and comprehensive experience that speaks to students natural interests and goals, particularly their desire to apply their engineering knowledge and skills in an authentic and challenging way, which is something students did not feel they could get through many other avenues.

This is not to imply that students' formal coursework experiences are not valuable to students. In fact, many students were quick to mention how important it was that they learn specific content and skills that can only be done through traditional educational approaches. Additionally, students mentioned how thrilled they were when they were able to transfer their skills and knowledge from classes into their work, and vice versa. With that said, the extracurricular environments afford students a space to be exposed to authentic engineering work, and to apply their prior knowledge and skills in ways that capture personal interests. Additionally, students had the opportunity to discover and express themselves as innovative and capable engineers. Students perceived this as a unique and desirable opportunity, one that is often endorsed by the engineering education community but insufficient in most engineering curricula (NAE, 2005). By being a part of extracurricular engineering environments students were also given the unique opportunity to realize the gaps in their skills and knowledge, and to reflect on how they can account for those gaps.

In terms of what extracurricular engineering environments can do to enhance the affordances and minimize the barriers of extracurricular engineering environments, we have several recommendations. First, it was evident that having a physical space allotted specifically for students to use regularly was extremely advantageous. Students who had physical spaces designated for their specific work tended to use this as a place to “hang out, mess around, and geek out” (Ito et al., 2010). Having a physical space not only allows students to designate a specific location as a “work space”, differentiated from other multi-faceted living spaces, but it also fosters a communal environment for students working on related or similar work, thus cultivating the community aspects of extracurricular engineering environments. Therefore, whenever possible, students pursuing extracurricular opportunities greatly benefit from having designated physical workspaces.

Also, support at the university-level is key to the success of these extracurricular environments. Although the student experiences are highly student-driven, faculty support is simply invaluable to the students. At the very least, student groups often need faculty sponsorship in order to acquire the funds, resources, and recognition needed to succeed.

Additionally, students need to be aware of the significantly positive influences extracurricular engineering experiences can have on their learning and professional development (Terenzini et al., 1996; Pascarella et al., 2005; Lattuca et al., 2006, 2010). Students also benefit from having that sense of validation when faculty and administration encourage and recognize the hard work that students do outside of the classroom.

- University-level recommendations include:
- Hosting events at the beginning of academic terms that showcase available opportunities
- Hosting events at the end of academic terms that showcase and recognize student work
- Allowing students to count their extracurricular work for some portion of their curricular credits
- Encouraging faculty members to advise, sponsor, or support student groups, and recognizing faculty members who do so

Faculty-level recommendations include:

- Actively get involved with a student group that does work relevant to your field
- Encourage students in your classes to pursue opportunities outside of the classroom
- Recognize students who do extracurricular work, and encourage them to share their experiences with the class when relevant
- If actively involved with a student group, guide students toward funding or sponsorship opportunities that can help enhance existing extracurricular opportunities

Student-level recommendations include:

- If actively involved in a student group, raise awareness of the group to help with recruitment and sponsorship efforts
- Identify, articulate, and re-visit personal goals and interests; this will help with identifying the appropriately aligned extracurricular opportunities, and will help make self-directed pursuits seem more strategically directed

4.6.3 Limitations and Future Directions

Our specific aim for this study was to enhance our understanding of students' experiences in extracurricular engineering environments for the purpose of identifying affordances and barriers to extracurricular engineering environments. As such, it was not our intention to assess or compare the quality of the extracurricular groups, nor the learning outcomes of the participating students. However, a potential future direction for this work would be to perform a longitudinal mixed-methods study that measures the extent of students' self-efficacy development due to participation in extracurricular engineering environments. A more intentionally comparative study could also be done to assess the quality of the unique extracurricular engineering opportunities available to students.

Another limitation of this study is that it was specifically within the context undergraduate engineering students from a large research-based state university, therefore findings from this study might not directly translate or reflect situations outside of this context. Possible future directions of this work could include multiple and diverse institutions and programs of varying contexts to better understand the impact of extracurricular engineering experiences in a more generalizable sense. We were also specifically interested in engineering-specific extracurricular experiences, although we are aware that undergraduate engineering students are multifaceted individuals with diverse interests and thus are likely to participate in various extracurricular experiences that might be outside of engineering contexts. Future work should consider how extracurricular experiences in general, not just those that engineering-specific, influence engineering students' experiences and professional development.

Lastly, despite race and gender issues not being a factor that was explicitly considered during this study, we could not help but notice how substantially limited these environments were in terms of racial or gender diversity. The investigated groups were predominantly Caucasian males, with the exception of the BME-UR, which had an equal representation of male and female students (although racial diversity was still limited). Although this was not surprising within the given context, we are still concerned that underrepresented students in engineering are missing out on experiences that could potentially greatly influence their learning and professional development. Future work should investigate barriers to entry of extracurricular engineering environments, as well as the decision making behaviors engineering students exhibit when considered extracurricular participation.

It is our hope that our work might serve as an example for how engineering education researchers might approach studying informal learning environments in engineering. Additionally, we hope this work might serve as a foundation for future research questions relevant to extracurricular engineering environments, including the research questions discussed in this section.

4.7 Conclusions

The ethnographically-informed study presented in this paper has shown how undergraduate engineering students experience in five different extracurricular engineering environments, as well as the affordances and barriers of these extracurricular environments. Out findings indicate that by providing a space for students to express their engineering selves in primarily self-directed ways, students have the opportunity to develop as even stronger self-directed learners, which in turn helps students develop a strong sense of self-efficacy in engineering. Also, the community and peer network that students inherently join by participating in extracurricular engineering environments further facilitates individual students' validation of their perceived experiences. Engineering programs and engineering faculty should consider approaches to encouraging students to pursue out-of-classroom engineering experiences, and recognize the extracurricular achievements of students already pursuing out-of-classroom engineering challenges. Existing extracurricular opportunities should also consider the discussed findings and recommendations in order to enhance the affordances and minimize the barriers of extracurricular engineering environments.

CHAPTER 5: EXTRACURRICULAR ENGINEERING ENVIRONMENTS AND NAVIGATIONAL FLEXIBILITY IN ENGINEERING EDUCATION

5.1 ABSTRACT

Background Compared to other disciplines, traditional undergraduate engineering curricula in the United States tends to be more rigid and inflexible. In this context, extracurricular engineering environments play an important role in many engineering students' educational experiences and likely provide students the greatest possibility of personalizing their educational experience.

Purpose Our purpose was to investigate students' experiences in extracurricular engineering design environments through the lens of navigational flexibility, with the goal of characterizing the affordances and barriers of these environments in terms of students finding personalized learning experiences.

Design/Method We used ethnographically-informed methods, specifically field observations, focus groups, and interviews, to investigate student experiences in extracurricular engineering environments. We also collected relevant archival data. We used a navigational flexibility framework informed by Stevens et al. to guide qualitative analysis of the collected data.

Results Students demonstrated multiple ways in which they were able to personalize their curricular and non-curricular experiences to achieve their self-defined goals and interests. However, institutional barriers, particularly time constraints and institutionally recognized achievements, stifle students' flexibility and willingness to pursue personally meaningful experiences.

Conclusion Extracurricular engineering environments afford navigational flexibility by offering students opportunities to work on motivating challenges with and among supportive

communities. By providing a space for students to express their engineering selves in primarily self-directed ways, extracurricular engineering experiences cultivate students' drive to find and pursue personally meaningful curricular and non-curricular educational experiences. We recommend that university and program level structures be reevaluated to encourage and provide students with more flexibility to find personalized learning experiences in and out of the classroom.

5.2 Introduction

Engineering programs in the U.S. have worked towards improving engineering education to better meet the demands of the modern engineering student and the engineering professional. Previous studies have indicated concern over the growing rigidity and inflexibility of the engineering curriculum of engineering programs in the U.S. (NAE, 2005; Duderstadt, 2007; Stevents et al., 2008). The insight provided by engineering education literature is that non-curricular learning activities and extracurricular experiences should strive to enhance existing curricular opportunities, filling in academic gaps that traditional curricular activities do not have the time or resources to address (Terenzini et al., 1995, 1996; Pascarella & Terenzini, 2005; Jamieson & Lohmann, 2009). This is particularly pertinent in Research I universities, where undergraduate curricular experiences might be limited with large class sizes and limited resources, but where copious extracurricular design and research experiences are available to students (Porter, 2006; Siegfried & Getz, 2006). It is known that many students engage in extracurricular learning experiences, and that these experiences have a significantly positive influence on students' educational and professional development (Terenzini; Lattuca et al., 2006, 2010). However, there is limited understanding of why extracurricular learning experiences are positively influential, particularly within the context of engineering education. Closely investigating extracurricular experiences can help uncover a more holistic view of the student experience, providing a more situated understanding of engineering students' educational experiences. Additionally, investigating engineering students' non-curricular experiences can better inform the prominent experiences that promote students to "become an engineer" (Stevens et al., 2008).

A better understanding of the multitude of ways in which students learning engineering is useful not only from a theoretical perspective but can also help guide curriculum design and mentoring efforts. For instance, it is well documented that student persistence and retention is a critical concern across STEM disciplines and engineering has been especially troubled by both migration of students out of engineering and an inability to attract students into engineering (Ohland et al., 2008). Previous studies have addressed this issue primarily at the institutional level (curriculum and instructional development), but recent studies take a more multidimensional view (Stevens, et al. 2008) emphasizing the student perspectives. Students are now seen as more directly engaged in the design of their "pathways" or personalized learning trajectories and leverage "navigational flexibility" available to them (Baxter-Magolda, 2001, 2004; Stevens et al., 2008), following "unofficial routes". Investigating these "unofficial routes" engineering students might take, as well as how and why students' seek unofficial routes, is vital in order to expand the understanding of the various contexts of engineering students' learning experiences (Stevens et al, 2008) and to holistically account for situated engineering learning (Johri & Olds, 2011).

The purpose of our study was to investigate undergraduate engineering students' experiences in extracurricular engineering design environments, particularly with the goal of characterizing the affordances and barriers of these environments that lend themselves to providing students with opportunities to define personalized routes through an undergraduate engineering program. While extracurricular engineering experiences do not directly create unique routes through a pre-defined engineering curriculum, these environments do allow students to find uniquely meaningful experiences that might influence students' attitudes, perspectives, and approaches towards earning an engineering degree. Aiming to better understand how these environments influence students' experiences, we used ethnographically-informed methods, treating these environments as unique cultures within the engineering program of a large research-focused state university in southeast U.S. Specifically, we conducted field observations, focus groups and interviews with participating students, and collected relevant archival data.

5.3 Background and Theoretical Framework

5.3.1 Extracurricular Engineering Environments

Extracurricular engineering environments are possible learning sites where engineering students might find informal learning opportunities within an engineering context. Such activities might also be referred to as non-curricular, co-curricular, or out-of-classroom activities, and are commonly used interchangeably in education literature. For the sake of consistency within this paper, and to remain consistent with the chosen vernacular of the study participants, extracurricular engineering environments will be used throughout this paper. Extracurricular engineering environments, for this study, specifically refer to any activity with educational intentions that is not an explicit requirement for engineering students to successfully complete an engineering degree.

Examples of extracurricular engineering environments include service-learning projects, undergraduate research experiences, design competitions, and professional learning experiences (such as internships and co-ops) (Dorie et al., 2012). Previous studies have found generalizable evidence of the positively significant impact of extracurricular activities on engineering students' learning outcomes, such as co-curricular involvement being a positive predictor of senior students' interdisciplinary skills (Lattuca et al., 2006, 2011). Although these studies provide evidence-based generalizable claims about the contributions of extracurricular activities, there are remaining questions left unanswered. It is clear that extracurricular experiences significantly and positively contribute to engineering students' learning outcomes; however, this does not provide a holistic understanding of engineering students' academic experiences with extracurricular activities (Strauss & Terenzini, 2005). The literature has also indicated that extracurricular experiences impact students' academic experiences and learning outcomes (Pascarella & Terenzini, 1991, 2005; Terenzini et al., 1999; Strauss & Terenzini, 2005; Kuh et al., 2008) yet there are remaining questions about the features and characteristics of extracurricular experiences that are the most influential on students' academic experiences and learning outcomes (Strauss & Terenzini, 2005; Bransford et al., 2005; Lattuca et al., 2011).

5.3.2 Navigational Flexibility in Engineering Education

Stevens et al. (2008) present a framework that describes students' experiences through engineering curricula, referred to as 'Becoming an Engineer'. This framework includes three dimensions: 1) the development of accountable disciplinary knowledge, 2) forming an engineer identity, and 3) navigational flexibility through engineering education (p. 356). We sought to further investigate the dimension of 'navigational flexibility', specifically the role extracurricular engineering environments might have for engineering students seeking navigational flexibility in engineering education.

By navigational flexibility, Stevens et al. (2008) are referring to the educational routes students take to successfully demonstrate accountable disciplinary knowledge (i.e. “actions that when performed are counted as engineering knowledge”, p. 357). Stevens et al. (2008) claim that individual students might choose to take unique routes through engineering education, differentiating between “official routes” and “unofficial routes”, as well as “unofficial strategies” to go through the official routes (p. 361). Official routes are those that are officially sanctioned through program-defined curricular requirements. He further describes three seemingly linear phases (as perceived by the student) that students go through to help identify their educational pathways: 1) goals/interests, 2) horizons of observation, and 3) critical transitions through obligatory passage points, as shown in Figure 5.1 (Stevens et al., 2008). Goals/interests refer to when students identify their goals/interests and intentionally pursue some educational experience to address these goals/interests (p. 361). ‘Horizons of observation’ refers to when students “develop an understanding of possible futures and increasingly identify themselves with these futures” (p. 363). Critical transitions through obligatory passage points refers to the significant changes seen in students’ developing engineering identities as they go through institutional rites of passage (p. 357).

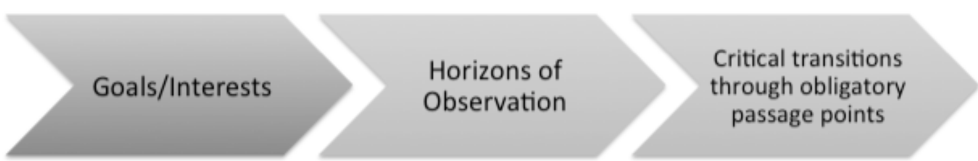

Figure 5.1. Observed Milestones of Students' Official or Unofficial Educational Routes, adapted from Stevens et al. (2008)

Stevens et al. (2008) present in-depth cases as exemplars of students as exhibits of different educational pathways. For example, the authors describe a student who struggled to be accepted into an engineering program at a large public university, but while working through his courses in a pre-engineering program in attempts to raise his GPA, the student was offered an opportunity to work in a mechanical stress testing facility. At this point, the student was in the first phase of knowing his goals/interests were aligned with getting an engineering degree. Although the student's GPA continued to be below an acceptable threshold, the student was eventually admitted into the engineering program because of his extensive experience working in an engineering research lab. This is representative of the 'horizons of observation' phase, where the student was able to identify himself as being capable of becoming a successful engineering student. Once the student was officially admitted to the engineering program, finally being institutionally identified as an engineer and reaching the 'critical transition through an obligatory passage point' phase, the student became one of the top students in his engineering classes, and was quickly recognized and selected for a prestigious engineering co-op.

This student's story is one that Stevens et al. (2008) classify as an "unofficial route" through engineering education. However, they also make note that although this student can be considered a successful case, his unique educational experience is not the only viable pathway to successfully becoming an engineer. Rather, they argue that students should have the flexibility to navigate through engineering education in ways that will be most advantageous to each individual student. Rigid institutional structures can result in students leaving engineering programs (and other STEM fields), whereas more flexible institutional structures can lead to more meaningful and successful student experiences (Stevens et al., 2008, p. 364).

Others in the engineering education community have considered the implications of navigational flexibility in engineering education. For instance, focusing on issues of persistence, engagement, and migration in engineering education, Ohland et al. (2008) and Adams et al. (2011) have noted that navigational flexibility encourages students interested in migrating into engineering. Others have considered the contextual factors of extracurricular participation that impact conceptual knowledge (Streveler et al., 2008; Godfrey & Parker, 2010). A student's successful navigation through engineering education by way of non-curricular experiences might be linked to strong self-directed learning since students choose the non-curricular experiences they wish to engage in. However, we believe students wishing to find navigational flexibility, and a student's successful navigation through engineering education via unofficial routes, are a distinct phenomenon worth investigating.

While the first two dimensions of "becoming an engineer" (accountable disciplinary knowledge and forming an engineer identity) are described by Stevens et al. solely from the context and perspective of students' curricular experiences, the last dimension (navigational flexibility) is described by Stevens et al. in a way that begins to insinuate the influences of non-curricular experiences in engineering students' educational experiences. Additionally, navigational flexibility is the dimension where Stevens et al. found the "greatest differences across students and schools" (p.361). Most striking was the particular timing in the significant decrease in participation in extracurricular activities by students from a large public university, with the decrease in participation occurring typically as soon as students were accepted into an engineering discipline (p. 362). Therefore, as this study is situated within the context of extracurricular participation by students from a large public university, these observations by Stevens et al. regarding navigational flexibility appear to have relevant implications worth investigating further.

5.4 Research Design

5.4.1 Research Goal

The purpose of this study was to investigate students' experiences in extracurricular engineering design environments using navigational flexibility as the guiding framework, with the specific goal of characterizing the affordances and barriers of these environments in terms of students having access to personalized "unofficial" learning experiences. Since our primary objective was to understand student experiences within a situated context, qualitative methods that provide rich descriptions are appropriate (Creswell, 2008; Johri & Olds, 2011). We used ethnographically-informed methods to investigate student experiences in extracurricular engineering environments, treating these environments as unique cultures within the engineering program of a large research-focused state university in southeast U.S (Baillie & Douglas, 2014). Specifically, we conducted field observations, focus groups and interviews with participating students, and collected relevant archival data over the course of two consecutive academic terms. We used the navigational flexibility framework informed by Stevens et al. (2008), which informed data collection protocols, provided *a priori* codes, and guided the qualitative analysis. Using a navigational flexibility framework allowed us to more closely characterize the particular affordances and barriers of extracurricular engineering design environments that uniquely influence student experiences in engineering education.

5.4.2 Ethnographic Methodology

Traditional ethnographic methods stem from anthropology, where researchers study and observe a select group of people and their natural behaviors as they go throughout their daily life (Case & Light, 2014). The ethnographer is concerned about understanding and describing how groups of people "live, how they talk and behave, and what captivates and distresses them." (Emerson, 2001, p. 1) When conducting an ethnographic study, the researcher is not really studying a group of people, but rather learning from a group of people about how they perceive an experience or phenomenon (Spradley, 1979; Glesne & Peshkin, 1992). Coming from an interpretivist epistemology, our purpose is to understand and situate descriptions of student experiences in extracurricular engineering environments (Johri, 2014). Our goal is to provide rich descriptions students' perceptions of their experiences, looking to understand a situated experience rather than to generalize an outcome to a larger engineering education context. Therefore, adopting ethnographic methods appropriately aligns with our research purpose (Borrego et al., 2009; Creswell, 2009). Traditional ethnography assumes a long involvement with a research site and subjects, which was not within the scope of the current work. Therefore, we adopted methods from ethnography with some modifications and have termed our approach ethnographically-informed.

The specific research sites that we investigated were four distinct extracurricular environments where students were working on engineering-specific tasks and goals. All groups were extracurricular groups, which is defined as educational groups in which students participated completely voluntarily. All student groups were from a single large research-focused state university in southeast U.S. We chose the four research sites because our research goal was to investigate common non-curricular educational experiences for engineering students from an R1 institution in the U.S., to bring to light what occurs outside of the engineering classroom, and to consider how these non-curricular activities are influencing engineering students educational trajectories (Bransford, 2007; Stevens et al., 2008; Johri & Olds, 2011).

5.4.3 Research Participants

The participants of this study were students from a large research-focused state university in southeast U.S. The four research sites, and the number of research participants from each site, are detailed in Table 5.1. The research sites explicitly emphasized exposing students to engineering design, and all were non-curricular (i.e. not a degree requirement, student participation completely voluntary). However, junior and senior-level students from the automotive design team (ADT), depending on the students' specific engineering discipline, were permitted to receive independent study or senior design credits for their contributions to the team.

Students from all research sites worked on primarily student-run projects. Students from the electrical engineering prototyping laboratory (EEPL) were provided peer mentors, who were typically more experienced undergraduate students, to provide team leadership and guidance. Students from the global service learning project (GSLP) and the additive manufacturing competition (AMC) had undergraduate student leadership; typically a student who was chosen by the student team or who organically rose to the occasion. The ADT regularly met with a faculty advisor, but were still very student-run, with a head undergraduate team leader who oversaw up to 10 undergraduate sub-team leaders who then oversaw the sub-team members. Students in all research sites came from various engineering disciplines, and represented all stages of an engineering undergraduate career. There were also a handful of non-engineering students (business, physics, math, and industrial design) participating in the other four research sites. Although student participants were not surveyed or asked to identify demographic details, it is important to note the general demographics of the participating students, who were predominantly white males. Of the 43 study participants, 8 were female, which is representative of each of the extracurricular groups. Considering all extracurricular groups together, there were few (less than 10) students from racially underrepresented groups (i.e. black or African American, Hispanic, Asian) seen participating during observations, where over 200 students were observed participating in the various extracurricular groups. The low gender and racial diversity observed in these research sites was however representative of the relatively low gender and racial diversity of this particular engineering program. Demographic issues pertaining to engineering education was not an intended aspect of this study, and therefore discussion of demographic issues will be limited in this paper, however it is still important to take note of the demographic context that this study is situated within.

Table 5.1. Study Research Sites

Extracurricular Environment	Description	Context	Study Participants
Automotive Design Team (ADT)	Team of undergraduate students working toward annual automotive design competitions	Common working space provided by university; industry and academic sponsorship	13 students from multiple cohorts (3 females)
Electrical Engineering Prototyping Laboratory (EEPL)	Groups of students working on various and unique self-defined engineering design projects	Common working space provided by university; academic sponsorship granted based on student proposals	4 students from one group (1 female)
Global Service Learning Project (GSLP)	Team of students working toward a global service project to design, implement, and evaluate sustainable power sources for a rural school in a third-world country	No common working space provided by university; industry and non-profit sponsorship granted on student proposals	8 students from various cohorts (1 female)
Additive Manufacturing Competition (AMC)	Teams of students working through a 10-week additive manufacturing design competition	No common working space provided by university; industry and academic sponsorship	18 students from multiple teams (3 females)

5.4.4 Data Collection

Adopting ethnographically-inspired methods, data collection involved conducting field observations, focus group discussions and individual interviews, and collecting archival data (Spradley, 1979; Borrego et al., 2009; Creswell, 2009). Focus group discussions with participating students were done for each research site, as detailed in Table 5.2.

Table 5.2. Focus Group and Interview Discussions by Research Site

Organization	Focus Groups	Interviews
ADT	45 min. focus group with 6 students	30-75 minute interviews with 9 students
EEPL	50 min. focus group with 4 students	30 minute interviews with 2 students
GSLP	50 min. focus group with 8 students	90 minute interview with 1 student
AMC	7 focus groups with 18 total participating students; (2 - 4 students per group; 30 mins - 1 hr)	90 minute interview with 1 student

The focus group and individual interview protocols were informed by the navigational flexibility framework, primarily focusing on any demonstrations of students' goals, interests, and transitional experiences in each situation. Focus groups were used to understand the collective student experience in each research site. The focus groups were semi-structured, lasted 30-60 minutes, and were audio-recorded. Overall, 36 students participated in focus group discussions, spread through 10 separate focus group sessions. Interviews were used to more closely understand individual students' experiences. The interviews were semi-structured, lasted 30-90 minutes, and were audio-recorded. Overall, 13 students were interviewed. Example questions and prompts during the focus group discussions were:

- What comes to your mind when you think of when you first joined [respective group] and what drove you to join [respective group]?

- Considering your goals when you first joined, and the expectations you had, have you met your personal goals, and has the [respective group] experience met your expectations?
- How would you compare your learning experience in [respective group] and your learning experience in a typical engineering class?
- What kinds of things have made participating in [respective group] easier for you?
- What kinds of things have made participating in [respective group] harder for you?
- What do you think has been the most meaningful part participating in [respective group]?

For the individual interviews, the interviewer asked students to draw and discuss a timeline of their undergraduate experiences. As students brought up the variety of curricular and non-curricular experiences that they were involved in, example questions and prompts used to further interview discussions included:

- What were you hoping to get out this particular experience?
- What/who made you interested; who/what makes you interested in doing these specific events/activities?
- What kinds of things have you needed to do in order to join/maintain participation?
- What do you need to do to be able to do these upcoming events/activities?
- What are you hoping to get out of these upcoming events/activities?

Field notes were collected during field observations of each research site; observations were typically during any student meetings, work sessions, symposiums, local competition events, or social events occurring throughout the course of the study (Geer, 1964; Spradley, 1979). Field observations were used to inform focus group and interview discussions, but also provided a rich set of data collected in real-time naturalistic settings, enhancing the focus group data. Archival data, which consisted of Facebook pages, official websites, resource management sites, proposals, and reports or other documentation, was also collected, primarily as a means for better understanding the contextual and cultural factors at play in the research sites. This rich set of data allowed us to investigate extracurricular engineering design environments aggregately, but also comparatively, helping us identify and characterize the unique affordances and barriers of the research sites.

5.4.5 Data Analysis

Focus group and interview data from all research sites were transcribed for analysis, and all field notes and transcriptions were grouped together by research site. Although all data was aggregated for primary analysis of the affordances of extracurricular engineering design environments in general, keeping the data grouped by research site allowed us to identify unique affordances and barriers for research site. Using a variety of data sources allowed us to triangulate our findings to ensure research validity (Leydens et al., 2004; Creswell, 2009).

All transcribed data was coded using *a prior* codes informed by the navigational framework previously described as shown by Table 5.3. The navigational flexibility framework was used to guide thematic coding. To reduce the effects of researcher bias (see Appendix A), it was important to ensure trustworthiness and validity during data analysis (Creswell, 2008; Johri, 2014). To maintain trustworthiness, two researchers performed data coding separately, and any discrepancies were discussed and resolved. Also, individual reports discussing the findings for each research site were sent to pertinent members of each research site for member checking. A secondary coding of the data was then performed to identify other emerging patterns within and among the five research sites. Triangulation between the focus group data, observation data, and archival data was conducted to further identify and validate emerging patterns outside of the *a priori* codes.

Table 5.3. ***A priori*** **codes, informed by navigational flexibility (Stevens et al., 2008)**

Category	Codes	Sub-Codes
Navigational Flexibility	Goals/Interests	Emerging curiosity
		Lifelong goal
	Horizons of Observation	Suggestions from mentors
		Suggestions from peers
		Prior knowledge/interests
		Suggestions from parent/teacher/family member
	Critical Transitions through Obligatory Passage Points	Application
		Acceptance
		Promotion

5.5 Findings

Investigating students' experiences in extracurricular engineering environments through a navigational flexibility lens helped identify the various influences extracurricular experiences had on students' educational trajectories. It was evident from the data that students often sought out additional experiences outside of the classroom, feeling unfulfilled with their classroom engineering experiences. This was due to a variety of reasons, such as unsatisfied expectations of the curriculum, evolving personal goals and interests, or simply becoming jaded with required coursework. Extracurricular engineering experiences allowed students to take control of their learning trajectories and uncover personally meaningful activities that then serve as a means to connect with disciplinary knowledge. As expected, students often pursued extracurricular environments based on prior goals or interests, and social factors often played into students' decision-making when joining particular groups. Through the experience of participating in an extracurricular activity, students often passed through critical transitions within and outside of the extracurricular group, which would then act as the catalyst for students' identity formation. By having the opportunity to participate in a primarily self-driven working environment, students were able to identify and pursue the most personally meaningful learning experiences within engineering education.

Using navigational flexibility as a guiding framework also allowed us to be able to identify affordances and barriers of extracurricular engineering environments. Specifically, limited time to pursue non-curricular experiences is a major barrier to students participating in extracurricular environments. However, extracurricular environments afford students the opportunity to work within a smaller engineering community, which appeared to influence students' identity formation. Extracurricular environments also afford students the opportunity to experience authentic engineering work, which then influences the ways students pursue their engineering education. The following sections will provide examples of how extracurricular engineering environments influence students' educational trajectories, as well as further describe the affordances and barriers of extracurricular engineering environments in terms of navigational flexibility.

5.5.1 Goals and Interests

As expected, many students sought out particular extracurricular activities based on prior personal goals and interests. Students referred to similar previous experiences in high school or summer camps, or pointed to key moments earlier in their lives that sparked a lifelong interest toward a particular area of engineering.

> "I mean since I was pretty young maybe I don't know the end of elementary school beginning of middle school my dad took me to the new york auto show and I kinda got really really interested in

the whole automotive thing and I got a subscription to car and driver that I read cover to cover every month so when I heard about this I really wanted to get involved, because of that, I wanted to work on the, I didn't really get a chance to work on them as a kid because we didn't have a garage or anything, but I wanted to work on it you know get my hands dirty with something like this." [FG-ADT]

"I had known about the team since high school and that I might want to do that." [I-ADT]

"Well I knew when I first joined, I loved like the, we did the work camps when I was in church in high school, you know building houses and things like that, and I just knew that I would love this cause it was along the same lines only related to my career path, so it was perfect." [FG-GSLP]

"I think I just had a couple projects like my senior year of high school. I built a table tennis robot that I took to the international science fair, like, that's always something that people [think is cool], so that probably helped." [I-EEPL]

Also as expected, students were also becoming jaded or disappointed with the engineering curriculum. The majority of the study participants were in their 2^{nd} or 3^{rd} year into the program, which is a common time for attrition in engineering education (Felder et al., 2000). Students were losing interest in their coursework, and did not feel as though they had much agency in relation to what and how they learned, nor did they feel as though they had much space to explore the engineering field outside of the curricular content. Rather than give up on engineering, however, these students sought out opportunities to apply engineering skills outside of the classroom.

"It's definitely a lot more interesting. Design projects, they're fun, but they're different topics. This is more of something that I would have done on my own, something I did do on my own. And things that we're assigned in our classes, are not necessarily something I would do in my free time, so… And this, it seems a little bit more relevant, because the design projects that we have done [in class], we haven't done much in the way of prototyping, and this is more hands-on." [I-AMC]

> "I was kind of tired of engineering, so I was like, I need something else to keep me motivated to do this…I think everybody should do [a design competition team]. It just teaches you a lot. And it's a lot of fun…I think like it just motivates you so much to do what you're doing, keep doing it, and not just sit in classes and hate it. That's it. I just really like it. And I'm really passionate about it. I mean I get up every day for it." [I-ADT]

Students also mentioned joining extracurricular engineering environments in order to enhance their resume. In general, students joined extracurricular engineering environments that aligned with personal interests in order to fulfill a variety of personal goals, such as resume building, gaining experience with particular skills, or gaining experience with applying engineering content to authentic engineering challenges. Students from the GSLP were also very driven by a desire to help others, and to apply engineering knowledge and skills in ways that can make societal differences.

> "I've always working on projects that can help others, I mean, that's a reason and drive behind all the other projects I've been involved with, science fair and other stuff. It just seemed [GSLP] would allow me to do that because it gives you a group of like-minded individuals who could make it possible to do bigger projects where you're affecting more people and helping out in a larger sense, and it lets you see and experience other cultures." [FG-GSLP]

Based on the experience of the study participants, students did not join extracurricular engineering environments on a whim or out of some external necessity. Rather, students joined primarily because of an intrinsic motivation to pursue an authentic engineering experience, and were initially driven to find opportunities out of the classroom that aligned with self-defined goals and interests.

5.5.2 Social Influences

While it was evident that the participating students were highly self-driven, this is not to say that the students were not strongly influenced by various social influences within and out of the extracurricular engineering environments. Not surprisingly, when asked about why they joined their respective extracurricular environment, or why they pursued a particular role within the environment, students often pointed to peers who presented a model for how an engineering student might manage adding extracurricular activities, or joining with friends to help overcome initial intimidation factors.

> "…well I would come around with [my peer mentor from a [first-year engineering freshman mentoring program], so he was on the team my freshman year, and I had known about the team since high school and that I might want to do that. And so he was on the team, he took me around a little bit here and there, I wasn't fully on, volunteering on and off." [I-ADT]

> "so I went to the meeting, I saw [my friend] there - we had a mutual friend, I've known her since pretty much freshman year. So I was like 'yeah maybe I'll come out to the [meetings], I like solar stuff, I like sustainable energy things'." [I-GSLP]

> "I don't know. It's what my friends did, so I kind of joined it." [I-EEPL]

> "I was like the least experienced, so I learned a lot from my teammates…I think learning new things, and, like stepping out of your comfort zone, because there's like a psychological resistance…that would be the one most meaningful thing for me." [I-AMC]

With regard to students' holistic educational experiences, students also mentioned the important social influences that impacted both curricular and non-curricular decisions that students made. For instance, the time and effort one student was putting into the ADT, was taking away from the time and effort he was putting into his curricular obligations. However, the time and effort this student was putting into the ADT was helping him realize his true potential and passion within engineering.

> "I was kind of faltering a little bit - [ADT] had really taken over a lot of the academics, and I got on kind of a probation thing, for academic stuff, and I talked to [undergraduate advisor] a lot about it, looking for something different to boost up or seek a different path cause I was treading water. And

she recommended [Industrial Engineering] cause I talked a lot about the management things, systems type thinking, manufacturing [things I was doing for ADT]." [I-ADT]

With the help of his undergraduate academic advisor, this student was able to make the necessary curricular changes that eventually set him up for success in his curricular *and* non-curricular pursuits. Similarly, more experienced students in these extracurricular engineering environments often serve as models for less-traveled pathways through the engineering curriculum, pathways that are more likely to foster success and satisfaction rather than attrition. For instance, both the EEPL and the AMC maintain some form of documentation of courses that previous students have taken, a resource used by current students when trying to make course selections for upcoming terms. During field observations conducted around the time of the term when students are thinking about what to sign up for the upcoming term, there were numerous conversations about which courses, seminars, or instructors should be chosen or avoided.

> "Next semester is when EE splits from CPE. I was thinking of CPE at the beginning, but I'd be behind a class. But I just want to do what I like, but I really like the hardware part a lot more. And you can still do both. People keep telling me you have to choose one or the other." [I-EEPL]

> "Just being able to ask someone. Because if there's something I'm having a problem with, odds are one of the seniors on the team has had that problem somewhere down the road, or somewhere in the past, so it's likely I can just ask someone and they'll be able to point me in the direction towards someone who's you know been down the same path." [I-ADT]

> "I've been managing my time so much better. Especially with the AMP lab because everyone is doing the same classes, so if you see someone struggling on work, you're like 'What are you doing over there? What should I be stressing about next?'." [I-EEPL]

Although students' curricular obligations were relatively rigid and structured, social influences helped students identify ways they could personalize their learning experiences through participating in extracurricular activities, as well as helped students identify less common but viable pathways through the engineering curriculum.

5.5.3 Critical Transitions & Identity

A salient characteristic that describes students' experiences in extracurricular engineering environment is the role these environments play in shaping students' engineering/professional identities. Much of students' engineering identities are attributed to the critical transitions students experience in their engineering programs. For example, all engineering students from the study's institution are required to go through a first-year engineering program before deciding on a specific engineering discipline. Students need to apply to the specific engineering disciplines, so being accepted into a particular department can be a significant achievement to some students.

> "I was pretty decided on ME, and I was really happy when I got into the department. That was kind of the stamp on [knowing I wanted to do mechanical engineering] too." [I-EEPL]

However, extracurricular engineering environments also appear to play a strong role in shaping students' engineering identities. These opportunities are often the first, or one of the few truly authentic engineering experiences that students have as undergraduate engineering students. Some study participants, particularly younger students early in the academic term, mentioned during focus group sessions that they were "not a real engineer, yet", or that "they haven't done any real engineering, yet". This included second-year students who had been accepted into a specific engineering department, and had successfully completed a number of engineering-specific courses. After becoming a part of these extracurricular engineering environments, these same students changed their perceptions of themselves, realizing that they were capable engineers who have the potential to work on innovative and challenging engineering work.

> "I'm not – people in this major have been doing this stuff for so long. People in the [EEPL] are crazy smart, I have no idea what they're talking about sometimes, so sometimes I'm like 'uh do I really fit in here? Is this really what I'm supposed to be doing?' but then I can't picture myself doing anything else." [I-EEPL]

> "We're both pretty beginner-ish with 3D printing, so that initial hurdle of, you know, what are the tolerances actually on this machine, as opposed to what we're being told? How thick can we actually make this? Do we have any confidence that this is actually going to work?…I think the challenge like this really sort of takes you out of the 'I've just done this in classes so I know what I'm doing'…you hit something real, and you have do the whole thing from scratch…it's much more open ended. And it really, you get more control, but at the same time you have to make decisions. And it sort of shows you what an engineer really has to do. There's no way to know what you don't know until it's right up your face and you're asked to do it and you just have no idea." [I-AMC][1]

The more involved students become in their respective extracurricular engineering environments, the more that particular community shapes their identity. This is especially true of extracurricular environments that have long-term commitments and/or designated workspaces. As students begin to see themselves a part of that particular community, they also begin to see themselves as a part of the engineering community as a whole, quickly becoming a large part of how they define who they are as a person and as a professional.

> "I definitely think that engineering to me isn't a career path, it's like almost a way of life, you know, it really influences a lot of the things and the person that you are. So, being a part of [GSLP] really helped bring that side of engineering out for me. That I'm not just - it's not just what I do; it's who I am." [FG-GSLP]

> "It's not that I am confident as [an electrical engineer]. It's that I can't picture myself *not* doing it. I feel like I'm doing everything that I want to do." [I-EEPL]

[1] It should be noted that this particular team won one of the top 3 prizes in their category during the AMC final competition event

As students' identities evolve to be more closely tied with engineering and with their respective extracurricular environment, they experience critical transitions within these environments that further shape their professional identities. These transitions can come in various forms: pursuing leadership roles, seeing a project through all stages up to completion, or accomplishing a specific milestone task.

> "When I came on in the spring 2011…I went in, introduced myself to team leaders, was kind of strategic, just to make sure I knew the top folks, and meeting everyone else as well, and then just getting in there pretty much every night. Maybe finish homework, maybe not, just head over to the lab, and learning how to lay up carbon fiber with them, spend time in the machine shop, talking to them about their design work; even designing a couple pieces for that year's competition car myself, and then working on it. And talking with all the guys about previous experiences, kind of where I wanted to go and everything, and then I went to competition…By the end of the fall semester, one of the older guys said, 'Alright we're looking at team leaders for next year…you seem like you can work well with people', so it was pretty clear. I was kind of appointed." [I-ADT]

> "…I went back to [GSLP country] again [second summer], and that was fantastic. It kind of brought to a close that whole project. We got to install everything, I had been there from assessment to implementation. They like threw a party for us in the end." [I-EWB]

> "It's really nice to see that all your effort you put into the minutiae come out. Actually, the first time we got this back the motor mounts weren't attached because of some error in the print. And that was kind of heartbreaking to get back it was like 'ugh we did everything perfect and something terrible happened.' But we got another model back that was complete. I was beaming! It was incredible. Just seeing something so - math is abstract - seeing something so abstract come into reality, like physically out of this file to this machine to your hands, is incredibly rewarding." [FG-AMC]

In general, in addition to curricular experiences, non-curricular experiences played a prominent role in these students' educational experiences, one that strongly influenced students' engineering and professional identities.

5.5.4 Affordances and Barriers

Extracurricular engineering environments provide affordances to students, particularly in terms of navigational flexibility through engineering curricula. As previously discussed, extracurricular engineering environments provide spaces for students to experience authentic engineering work, and to express themselves as engineers. Extracurricular activities that are more long-term have the potential to give students an opportunity to be a part of an engineering community, one that reflects professional engineering workspaces. Extracurricular activities that are more short-term give students the opportunity to explore and experience a variety of engineering challenges and workspaces. Either situation affords engineering students an opportunity to personalize their education in ways that best help them identify and align their interests and experiences, in ways that is not traditionally possible in large R1 institutions.

> "I actually think it's kind of interesting that I'm doing [civil engineering service learning project] and the [EEPL], and that's like electrical and civil, but I'm mechanical." [I-AMP2]

However, there are also barriers that tend to complicate students' educational experiences. The most salient barrier is time, specifically the limited amount of time available for students to fully pursue all of their educational goals. In order to get the most of any of the extracurricular engineering experiences, students need to put in a significant amount of time and effort into the engineering challenges. This time being put into these extracurricular activities is time that is not spent on curricular obligations that are occurring simultaneously. Most students optimistically claimed that this was an opportunity to develop good time management skills.

> "For me, the [EEPL] helps me manage my time, because I want to work on my project, and I have to finish everything first, I mean, I have to, like I can't just not do my work and do this. I'd feel so bad." [FG-EEPL]

However, some students admitted that their academic goals were faltering as a result, such as the previously mentioned student who ended up changing engineering disciplines. Other students had similar experiences.

> "...time was the hardest thing. And it's a good thing I dropped Dynamics, because that opened up a lot of time for me to work on this project. But that was probably the biggest barrier, was time, and for other people I think it might be intimidating." [FG-AMC]

> "I kind of sometimes am one of those people who's like 'well… [expletive] differential equations, I don't really care anyways.' You know I can do matrices, so I'm just going to work on this instead. Sometimes balance is difficult staying interested with a heavy course load…When you have a connection, when you've traveled, you want this to happen. You want people to have electricity, it's kind of, if you don't do it, then no one else will." [FG-GSLP]

This was particularly frustrating to students who highly valued their non-curricular experiences above their curricular experiences.

> "I'm quite kind of bitter about it actually. Just some of the institutional 'oh GPA is always the guiding factor in everything'. Like if you don't have that you can't get scholarships and stuff. And in my heart I would see people, even when I was doing well freshman year, I would see people who are getting 3.8s, 3.9s, whatever, and I would say 'I wouldn't trust them with a hammer'…So it was kind of, I don't worry about it as much anymore; it definitely ruined the Mechanical Engineering track for me. For a while I was really angry about it, but then I started working back into [Industrial Engineering]. And it's worked out fine." [I-FORMULA]

Other students simply accepted the fact that their time was limited, and chose to extend their academic careers by a year or more in order to successfully accomplish as many of their educational goals as possible.

> "…if you're on track in engineering you're behind. You're just behind all the time. So I wanted to at least, if I can't get ahead in ECE, to do other things and find other things I'm interested in. Cause I don't know, I feel like that sticks out. And yeah, I couldn't do just ECE, I like other things too. I don't like limiting myself." [I-AMP]

> "This is the other reason why I did kind of poorly my sophomore year and I figured that out my junior year. I was so obsessed with being on track with my peers; other people are taking 15 or 18 credits of engineering, I should be able to do that too. And that was killing me. When I switched to 9 to 12 engineering credits, I all of a sudden didn't drop the ball completely on one class. And every semester after that I made dean's list and made over a 3.0 GPA. I kind of figured that out my junior, because I tried it again, and it didn't work again." [I-EWB]

Despite the affordances that extracurricular engineering experiences provide students, the amount of time that these experiences take away from students can potentially be too large a barrier. This barrier can oblige students to make the decision of drastically altering their academic plans, or to solely focus on curricular responsibilities.

5.6 Discussion

The analysis previously described in detail identified how extracurricular engineering environments influence navigational flexibility capabilities of engineering students. The findings provide implications towards the value of extracurricular engineering experiences. In the following sections we will also discuss the implications for practice, specifically approaches towards enhancing the affordances and minimizing the barriers of extracurricular experiences in terms of navigational flexibility in engineering education. Lastly, we address the limitations and future directions of this work.

5.6.1 How Extracurricular Experiences Influence Navigational Flexibility

Based on the findings of this study, extracurricular engineering experiences play a pivotal role in allowing students to discover and have access to meaningful "unofficial routes" through rigid curricular structures. Figure 5.2 shows a visual representation of the role of extracurricular engineering experiences on navigational flexibility through engineering education, from the perspective of undergraduate engineering students.

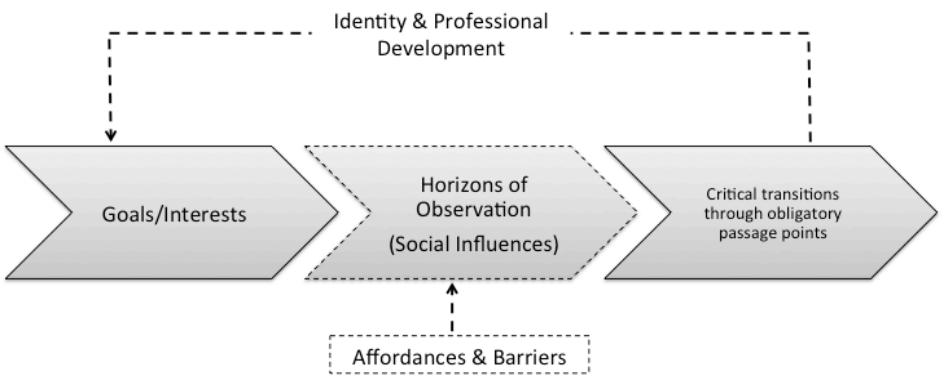

Figure 5.2. Visual representation of how extracurricular experiences influence navigational flexibility from the perspective of an undergraduate engineering student.

The study participants demonstrated how their individual goals and interests lead them to pursue extracurricular opportunities. The extracurricular opportunities provided students spaces to work on authentic engineering challenges that aligned with their goals and interests. More importantly, these environments provided students unofficial routes that were accessible and personally meaningful, which are important factors that influence motivation and retention in engineering education (Baillie & Fitzgerald, 2000; Stevens et al., 2008).

Once these goals and interests have been identified, students use a variety of "horizons of observation" to identify the experiences that best align with these goals and interests (Stevens et al., 2008). This area of navigational flexibility is where extracurricular experiences can be the most influential. One of the most salient affordances of extracurricular engineering environments is the opportunity for participating students to form and become a part of a specialized community. This inherently means that students tend to become emotionally close to their extracurricular peers, and are strongly influenced by the opinions and advice of those peers.

Their desire to succeed and to pursue upward mobility within extracurricular environments is partially a result of the extrinsic motivating force of wanting to impress their peers, and more importantly, to be a contributing member of the defined community. Other studies have indicated the strong influential impacts that social interactions can have on students in educational contexts (Bandura, 1977; Wenger, 1998; Wenger, 1999; Crede et al., 2010; Lattuca & Litzinger, 2014). Outside of the extracurricular environment, students also pursue curricular and/or additional extracurricular opportunities based on recommendations and opinions of their peers as well as by any authoritative figures (i.e. faculty advisors, industry mentors, staff) that students frequently interact with during extracurricular participation. Students appear to strongly trust the opinions and advice from the people students closely interact with that are significant figures within extracurricular environments, because students perceive these individuals as like-minded and experienced role models. Since the people students interact with in extracurricular environments have the opportunity to get to know participating members at a more personal level, extracurricular environments afford students more opportunities to experience relevant “horizons of observation”, allowing them to identify meaningful and accessible alternative pathways through engineering education that best align with their goals and interests (Bandura, 1977; Stevens et al., 2008; Marra et al., 2012; Lattuca & Litzinger, 2014).

The affordance of small, like-minded communities that extracurricular environments have also has an influential role as students’ experience “critical transitions through obligatory passage points”. As student pass through critical transitions, these milestones act as catalysts to their professional and engineering identity development (Wigfield & Eccles, 2000; Stevens et al., 2008; Newstetter & Svinicki, 2014). Students gain a sense of self-efficacy as they accomplish and experience significant milestones, both in their curricular and extracurricular experiences. It should be noted that these milestones, or obligatory passage points, are institutionally defined constructs. At the curricular-level, students engineering and professional identities have opportunities to develop as they accomplish certain institutional transitions, i.e. being accepted into a department, passing the first "truly engineering" course, completing required credit hours, etc. However, accomplishing mandatory curricular tasks does not seem to be enough to many students. Students desire more hands-on and authentic applications of disciplinary knowledge, as a way to test themselves of their capabilities as an engineer (Bandura, 1977; Wendell & Kolodner, 2014). Extracurricular environments offer students the opportunity to do this, in low-stakes, friendly, and personally fulfilling environments. When students accomplish tasks and succeed in extracurricular environments, they then receive recognition from their community of peers and faculty advisors. This recognition then becomes a substantially more meaningful passage point that strongly influences students' identity development.

One important distinction of the modified framework represented in Figure 5.2 as compared to the framework described by Stevens et al. (2007) represented in Figure 5.1, is that navigational flexibility does not appear to be linear but rather more iterative. As described above, the affordances and barriers of engineering extracurricular groups has influences on students' "goals/interests" and "horizons of observation" at various and spontaneous instances in time. This is particularly evident when considering the time commitments students either can or cannot afford. This is also evident when considering the peer mentoring and community aspects of these extracurricular. Peer mentoring can have a substantial influence on students educational experiences (Lai & Law, 2006; Meyers et al., 2010; Brandt et al., 2013), and appears to be an essential component regarding the success of a student's experience in an extracurricular engineering group. Additionally, participating students are not static beings; dynamic identity and professional development occurs throughout students' time in engineering extracurricular groups. Each success and set-back, big and small, that the students experience has some influence on how students adjust their goals and perceptions of their capabilities. So rather than being a linear phenomena, this study seems to indicate that extracurricular experiences have a much more dynamic and iterative influence on navigational flexibility from the perspective of an undergraduate engineering student.

Another critical distinction of the modified navigational flexibility framework is the important outcome of engineering identity and professional development exhibited by students participating in extracurricular activities. This construct was not one that was directly noted by Stevens et al. (2005) when discussing navigational flexibility, but was rather considered to be a separate dimension of "becoming an engineer". Stevens et al. discuss identity within the context of students identifying themselves as engineers or as engineering students with respect to their discipline, as a result of their acceptance into an engineering program or major (p. 360). However Stevens et al. speak little on the meaningful influence non-curricular experiences have on students' developing engineering identities. As this study indicates, to students who invest heavily on extracurricular pursuits these experiences are more substantial and personally meaningful indications of their engineering identities and capabilities as compared to their curricular experiences. Thus, extracurricular experiences can have a strong influence on how students navigate through an engineering program, guiding the choice in discipline, course electives, and the pace at which students complete the program.

5.6.2 Implications for Practice

Considering that extracurricular engineering environments can have such an influential impact on navigational flexibility opportunities and students engineering identity development, this also implies that negative student experiences in such environments could thus negatively impact students' educational experiences. As such, our findings have several implications for practice in order to enhance the affordances and minimize the barriers of extracurricular engineering environments.

As previously discussed, one of the most salient affordances of extracurricular engineering environments is the opportunity to form and engage in a small community of like-minded individuals. Therefore, to maximize this positive attribute of extracurricular experiences, we recommend that existing extracurricular environments enhance or maintain factors that foster a sense of community. The most ideal situation is to have an extracurricular environment that is situated within a designated workspace that is available to students as much as possible. Designated workspaces observed for this study appeared to be the "hang out" spots for participating students. These spaces were essentially a second home for the students; they worked, studied, and socialized in these spaces, which fostered many spontaneous informal learning opportunities. Previous studies have shown the countless benefits of having designated workspaces (Ito et al., 2010; Crawley et al., 2007; Litzinger & Lattuca, 2014). However, we recognize that designated workspaces are not always possible for all extracurricular opportunities. In situations where workspaces are not possible, we recommend cultivating a sense of community as much as possible by hosting social work events, e.g. hackathons, brainstorming events, symposia events, workshops/seminars, group picnics, study sessions. This is by no means a comprehensive list of possible approaches. The idea is to offer students opportunities to come together and share ideas, goals, and interests. Encourage students to learn from more advanced students' experiences (perhaps with a senior-students panel), and make students aware that faculty advisors support participating students (hosting workshops and seminars is one possible approach). The idea is to offer students an extracurricular experience that is personally meaningful, one where students are able to frequently closely interact with a variety of like-minded individuals that can help them define and navigate their pathway through engineering education and towards professional opportunities.

In terms of maximizing the positive experiences that students have in extracurricular environments, specifically the opportunities to accomplish the critical transitions and milestones within these environments, we have institutional and faculty-level recommendations. Where the social interactions are one of the most meaningful aspects to students when participating in extracurricular activities, one of the most influential experiences most students have (influential to identity development) is having their work and achievements being recognized by their peers, faculty, institution, and potential employers. Currently, the observed extracurricular environments make use of symposiums, outreach events, and competition events to recognize students' non-curricular achievements. However, of the observed research sites, one did not have any event that offered student recognition, and already involved members of the community primarily attended events offered by the other research. We believe that more students would be willing to participate in extracurricular experiences if institutions more strongly recognized the work and achievements of non-curricular experiences, especially since dedicating the time to participate in such experiences appears to be a substantial academic sacrifice to many of the participating students. Literature supports this idea that institutional structures and culture substantially impact students' on-campus extracurricular experiences (Ro et al., 2013; Lattuca & Litzinger, 2014). Students who participated in one of the research sites were able to get some curricular credits for their participation (either as independent study or capstone design credits), with the exception of students from a certain engineering discipline. Offering curricular credits for extracurricular work is one approach to recognizing and encouraging non-curricular experiences. Institutions could also hand out appropriate awards recognizing exemplary non-curricular student work, and faculty might consider offering students opportunities to showcase relevant non-curricular work as class assignments. Faculty and other undergraduate advisory staff could also encourage and help students identify alternative courses or less traditional pathways through curricular requirements that meet both departmental demands and student goals/interests, which might help make curricular experiences more meaningful and aligned with students' non-curricular experiences. Institutional opportunities for students to showcase and be recognized for their non-curricular work potentially offer additional "critical transitions" for students to pass through, as well as help minimize (or at the very least mitigate) the barrier of time constraints.

University-level recommendations include:

- Hosting events at the end of academic terms that showcase and recognize student work
- Allowing students to count their extracurricular work for some portion of their curricular credits
- Encouraging faculty members to advise, sponsor, or support student groups, and recognizing faculty members who do so

Faculty-level recommendations include:

- Actively get involved with a student group that does work relevant to your field
- Encourage students in your classes to pursue opportunities outside of the classroom
- Recognize students who do extracurricular work, and encourage them to share their experiences with the class when relevant

- If actively involved with a student group, guide students toward funding or sponsorship opportunities that can help enhance existing extracurricular opportunities

Student-level recommendations include:

- Identify, articulate, and re-visit personal goals and interests; this will help with identifying the appropriately aligned extracurricular opportunities
- Identify and pursue curricular opportunities that align with extracurricular experiences, interests, and goals
- Discuss experiences, interests, and goals with faculty and instructors, and work together to identify relevant and meaningful opportunities within a course

5.6.3 Limitations and Future Directions

Our specific aim for this study was to enhance our understanding of students' experiences in extracurricular engineering environments for the purpose of identifying affordances and barriers to extracurricular engineering environments. As such, it was not our intention to assess or compare the quality of the extracurricular groups, nor the learning outcomes of the participating students. However, a potential future direction for this work would be to perform a longitudinal mixed-methods study that measures the extent of students' identity development due to participation in extracurricular engineering environments. A more intentionally comparative study could also be done to assess the quality of the unique extracurricular engineering opportunities available to students, as well as comparing navigational flexibility opportunities among institutions and/or extracurricular groups.

As noted earlier in this paper, the students participating in extracurricular engineering groups were predominantly white males. Future research should consider further identifying demographic characteristics and issues pertaining to extracurricular participation by students of underrepresented groups. Participation in extracurricular groups such as the ones described in this study can be substantial time commitments, an important barrier to entry discussed in this paper. Future research should consider investigating possible interventions that could mitigate barriers to entry, as well as investigate possible explanations for the apparent exclusion of underrepresented groups. While it is important to acknowledge and reward students who voluntarily spend additional time and effort outside of curricular demands, it is also important to ensure that we are not privileging the already privileged. This brings up challenging questions and issues pertaining to formalization of extracurricular participation, formalization of reward systems, and inclusivity of extracurricular groups that should be further investigated by future research.

Another limitation of this study is that it was specifically within the context undergraduate engineering students from a large research-based state university, therefore findings from this study might not directly translate or reflect situations outside of this context. Possible future directions of this work could include multiple and diverse institutions and programs of varying contexts to better understand the impact of extracurricular engineering experiences on navigational flexibility in a more generalizable sense. We were also specifically interested in engineering-specific extracurricular experiences, although we are aware that undergraduate engineering students are multifaceted individuals with diverse interests and thus are likely to participate in various extracurricular experiences that might be outside of engineering contexts. Future work should consider how extracurricular experiences in general, not just those that engineering-specific, influence engineering students' experiences, professional development, and navigational flexibility. It is our hope that this work might serve as a foundation for future research questions relevant to extracurricular engineering environments, as well as future research questions relevant to enhancing engineering students' access to navigational flexibility through engineering curricula.

Lastly, as noted earlier, findings from this study have implications regarding students' engineering identity development, which could not be fully captured by the navigational flexibility framework as it stands. Future research should consider how the complete "becoming an engineer" framework discussed by Stevens et al. (2005) might guide further investigation of the affordances and barriers encountered by students pursuing or wishing to pursue extracurricular experiences. While Stevens et al. discuss the other two dimensions not included in this study (accountable disciplinary knowledge and identification) primarily from a curricular context, this study indicates that all three dimensions (not just navigational flexibility) have relevant implications regarding students' non-curricular experiences within engineering education. Therefore, future research should fully employ the "Becoming an Engineer" framework to more comprehensively investigate the role of non-curricular engineering experiences on the "changes that occur overtime as students traverse their undergraduate educations in engineering" (Stevens et al., 2005, p. 355).

5.7 Conclusions

The ethnographically-informed study presented in this paper has shown how undergraduate engineering students experience common extracurricular engineering environments, as well as the affordances and barriers of these extracurricular environments in terms of navigational flexibility in engineering education. Our findings indicate that students participating in extracurricular engineering environments highly valued the opportunities to claim agency over their work and learning experiences, as well as how social influences from extracurricular environments positively influence curricular and non-curricular experiences. However, institutional barriers, particularly time constraints and institutionally recognized achievements, stifle students' flexibility and willingness to pursue personally meaningful experiences. By providing a space for students to express their engineering selves in primarily self-directed ways, extracurricular engineering experiences cultivate students' drive to find and pursue personally meaningful curricular and non-curricular educational experiences, as well as provide an approach to finding navigational flexibility within a rigid engineering curriculum. We recommend that university and program level attributes be reevaluated to better encourage and provide students with more flexibility to find personalized learning experiences in and out of the classroom.

CHAPTER 6: SUMMARY AND FUTURE WORK

6.1 SUMMARY

The purpose of this dissertation study was to better understand the holistic educational experiences of undergraduate engineering students, more specifically identifying where engineering design learning is occurring and how participation in non-curricular engineering-related activities influence students' educational experiences. The preceding chapters each addressed the three major aims of this study:

1. To identify where engineering design learning occurs

2. To explore students' experiences as they participate in non-curricular learning environments, specifically from a self-directed learner autonomy framework

3. To explore the ways undergraduate engineering students find navigational flexibility, or personalized learning trajectories, in engineering curricula

A summary of the findings with respect to the primary research questions is presented in Table 6.1. With regard to where engineering design learning occurs, the literature points to various educational contexts that effectively deliver engineering design education. The most common settings include capstone design courses, first-year engineering courses, and other non-traditional classroom experiences (e.g. Virtual laboratories). Strategies that involve authentic and longer-term engineering design experiences tend to be the most impactful in terms of student outcomes and perceptions, however those experiences are not always implementable at larger scale. More traditional educational approaches to engineering design learning, though less impactful, are still effective delivery methods for introducing key aspects of engineering design education (e.g. modeling, global/societal/economic/environmental factors, communication skills).

Table 6.1. Summary of Findings

Research Question		Data	Findings
RQ1:	*What are the defining characteristics and implications of existing educational environments designed for undergraduate engineering design learning in large research-focused universities in the US?*	• Literature review	• Engineering learning, particularly in terms of design education successfully occurs in a variety of educational settings • Capstone, first-year experiences, and non-traditional classroom experiences have all been shown to be effective environments to teach and learn engineering design • Strategies that involve authentic and longer-term engineering design experiences tend to be the most impactful in terms of student outcomes and perceptions • The earlier in their career that students are exposed to engineering design, and the more consistently they participate, the better the learning outcomes • However, research on non-curricular environments for engineering learning is less studied (Presenting a gap in the literature)
RQ2:	*How do students describe their experience with non-curricular eng. activities?*	• Observations • Individual student interviews	• Autonomy/Agency over work • Practical experiences that influence persistence in engineering
RQ3:	*What are salient features of engineering-related non-curricular activities?*	• Observations • Student focus groups	• Strong self-directed learning skills exhibited by students • Environments of extracurricular activities cultivate self-directed learning attributes by providing students a space to be exposed to an engineering community, authentic engineering work, and accessible resources • Influence on students' self-efficacy • Community and peer networks within extracurricular engineering environments facilitate students' validation of their perceived experience
RQ4:	*What role do non-curricular activities play in providing engineering students navigational flexibility?*	• Observations • Student focus groups • Individual student interviews	• Space for students to express engineering identities • Opportunities for personalized, meaningful learning within extracurricular experience • By providing a space for students to express their engineering selves in primarily self-directed ways, non-curricular engineering experiences cultivate students' drive to find and pursue personally meaningful curricular and non-curricular educational experience • Institutional constraints (time and merits) are the most salient barriers to students taking full advantage of seeking navigational flexibility through non-curricular participation

The earlier in their career that students are exposed to engineering design, and the more consistently they participate, the better the learning outcomes (i.e. communication skills, teamwork skills, innovative and critical thinking). As the previous chapters and the following paragraphs will discuss, the findings of this study indicate that students have substantially influential experiences in non-curricular settings, affording students to be exposed to engineering design early and consistently. As the literature has indicated that early and consistent exposure to engineering design is ideal in terms of learning outcomes and student perceptions, this dissertation study has identified that non-curricular environments can be powerful spaces for learning that already exists, preventing the need for extensive curricular changes. With the exception of service-learning experiences, there was limited literature considering other non-curricular educational settings where engineering design learning might occur. This presents a significant gap in the existing engineering education literature with regard to more non-curricular learning experiences, such as learning in designed settings, outreach learning, learning media, and everyday informal learning.

As an approach to address this gap in the engineering education literature, this dissertation study investigated five non-curricular engineering learning sites for undergraduate engineering students at a large research-driven state institution. Informed by the findings of a pilot study that investigated how students describe their experience with engineering-related non-curricular activities, I first investigated the salient features of engineering-related non-curricular activities from the students' perspectives using a self-directed learner autonomy framework to guide the study. Students participating in extracurricular engineering environments exhibited strong attributes of self-directed learners, particularly a willingness and ability to be challenged and to learn. The educational environments of the extracurricular opportunities cultivated these self-directed learning attributes by providing students a space to be exposed to an engineering community, authentic engineering work, and accessible resources. By providing a space for students to express their engineering selves in primarily self-directed ways, students have the opportunity to develop as even stronger self-directed learners, which in turn helps students develop a strong sense of self-efficacy in engineering. Also, the community and peer network that students inherently join by participating in extracurricular engineering environments further facilitates individual students' validation of their perceived experiences.

I also investigated the role non-curricular activities play in providing engineering students navigational flexibility through engineering curricula. Students demonstrated multiple ways in which they were able to personalize their curricular and non-curricular experiences to achieve their self-defined goals and interests. However, institutional barriers, particularly time constraints and institutionally recognized achievements, stifle students' flexibility and willingness to pursue personally meaningful experiences. Extracurricular engineering environments afford navigational flexibility by offering students opportunities to work on motivating challenges with and among supportive communities. By providing a space for students to express their engineering selves in primarily self-directed ways, extracurricular engineering experiences cultivate students' drive to find and pursue personally meaningful curricular and non-curricular educational experiences. We recommend that university and program level structures be reevaluated to encourage and provide students with more flexibility to find personalized learning experiences in and out of the classroom.

To summarize, this study aimed to better the understanding of engineering students' holistic educational experiences by identifying where engineering design learning is occurring, and how participation in non-curricular engineering-related activities influence students' educational experiences. By combing the literature on engineering design education, I found that engineering design learning can effectively occur in a variety of educational settings, but specific curricular contexts (i.e. capstone design, first-year engineering courses) are much more heavily studied than non-curricular learning contexts. This has left a gap in the engineering education community's appreciation for the meaningful and valuable learning experiences students have outside of classrooms, a gap that I started to address with this dissertation study. Through ethnographically-inspired investigations of non-curricular student groups, I was able to bring to surface a sampling of engineering students' perceptions and experiences. By taking account of students' experiences, I was able to begin to shed some light on the valuable features of non-curricular experiences that influence engineering students' educational experience, as well as to identify the prevalent barriers that students encounter while pursuing non-curricular activities.

Through this dissertation study I have also developed two possible frameworks and recommendations for further investigating extracurricular environments. My modified self-directed learner autonomy framework is particularly useful for identifying features of extracurricular environments that most beneficially influence students' educational experiences and learning behaviors. My modified navigational flexibility framework can be used to help identify other affordances and barriers encountered by students wishing to pursue extracurricular activities. The modified navigational flexibility framework can also be placed back into the more complete "Becoming an Engineer" framework (Stevens et al., 2005), and be employed as an analytical framework for future and more comprehensive research on students' holistic experiences through engineering education. Overall, this dissertation has contributed a greater understanding of where and how engineering design education occurs, a greater understanding of students' current experiences in non-curricular design experiences, and two possible frameworks to guide suggested future research pursuits on both formal and informal engineering design learning. The following sections will discuss the recommendations to practice and future research directions informed by the contributions of this dissertation study.

6.1.1 Summarized Recommendations to Practice

The findings of this dissertation study inform the following recommendations to practice at the university, faculty, and student level, as shown in Figure 6.1.

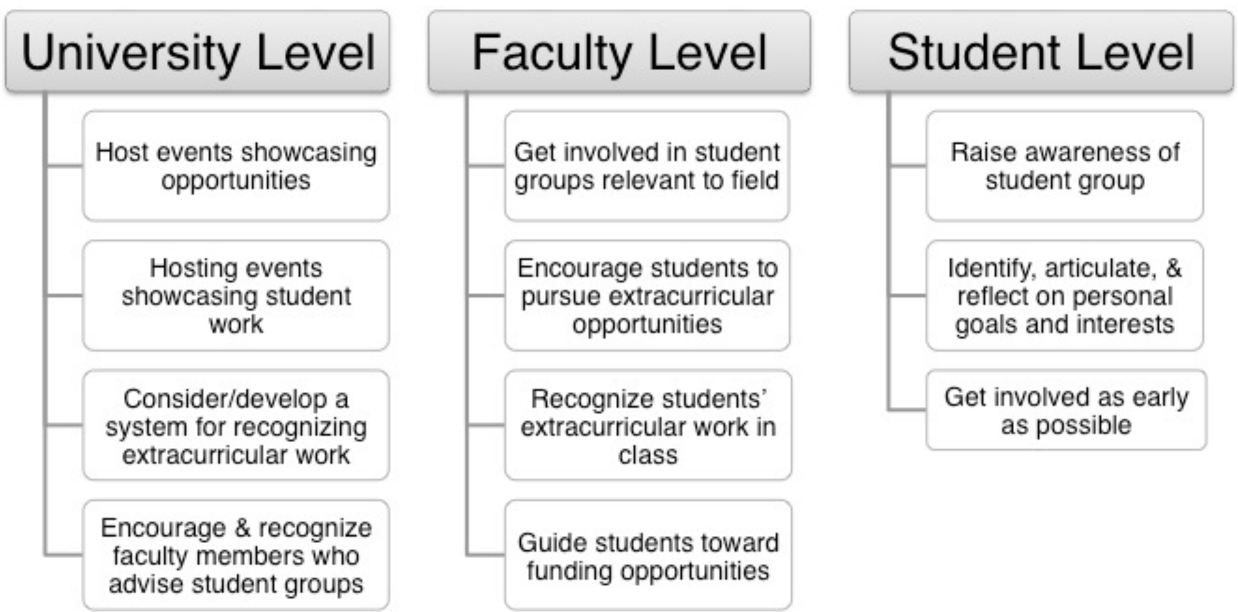

Figure 6.1. Recommendations to Practice

At the university level, based on the finding that students tend to have little aware of the many available extracurricular opportunities, I recommend that universities and engineering programs host annual or bi-annual events that help showcase available opportunities. As an approach to showing encouragement and support of students' participation in extracurricular opportunities, I also recommend that universities and engineering programs host annual or bi-annual events that showcase students' exemplary extracurricular achievements. While I do not recommend standardized measurements or requirements for extracurricular participation, I do recommend that universities and engineering programs begin serious dialogues that begin to consider possible institutionally recognized systems for acknowledging students' extracurricular investments. This will also include recognizing and encouraging faculty who are committed to advising extracurricular student groups.

At the faculty level, I recommend that more faculty members get involved in developing and advising extracurricular student groups that are relevant to each member's field of expertise. I also recommend that faculty consider different approaches to encouraging their students to participate in extracurricular activities, either by suggesting upcoming opportunities to students as a class or individually, or by allowing students to showcase relevant extracurricular work for course credit. It is my belief that a faculty member's engagement with extracurricular engineering activities is one effective approach to increase student engagement in class, as well as a great avenue for identifying exceptional students that faculty members might consider as undergraduate or graduate assistants in research labs. I also recommend that faculty further guide students to funding opportunities that might allow students greater financial affordance to pursue extracurricular opportunities.

At the student level, I first recommend that students identify, articulate, and reflect on their goals and interests early and often. Only through self-awareness can students begin to strategically explore opportunities that will help them discover their engineering and/or professional identities. Getting involved as early as possible in activities that speak to one's personal interests and goals is one of the best ways to find underlying passions that will drive educational and professional pursuits. For students already participating in extracurricular groups, I recommend to further enhance recruitment efforts. I recommend that these students continue to raise awareness of who they are and what their student group does by hosting informational events, by visiting large common courses (i.e. first-year engineering classes and other foundational engineering courses), and by showcasing their work and achievements at university-side events.[2]

6.1.2 Summarized Recommendations for Future Research

Future work related to this study should investigate the decision-making behaviors engineering students exhibit when considering extracurricular participation. Participating students represented in this study are a small portion of the general student body of the engineering program, and it is possible that findings from this study are only pertinent to the types of students who choose to participate in extracurricular engineering activities. Future work should consider uncovering the demographic characteristics of students who choose to participate in extracurricular engineering activities, as well as of students who do *not* choose to participate in extracurricular engineering activities. By understanding who is participating in non-curricular opportunities, engineering programs and non-curricular programs can be better informed when making recruitment and administrative decisions. Identifying the decision making behaviors of participating and non-participating students can also help uncover barriers to entry of extracurricular engineering activities, particularly any barriers affecting underrepresented groups of engineering students.

Future work should also consider further investigating the self-efficacy trends as they relate to extracurricular participation. Self-efficacy development was an emerging construct of

[2] One effective approach used by one of the research sites for this dissertation study was to invite marketing-major students to join their student group, creating a marketing sub-team that focused solely on recruitment, marketing, and advertisement for the student group. This helped increase awareness of the student group, created opportunities to interdisciplinary experiences, as well as provided authentic marketing experiences for the marketing students.

this study, however since self-efficacy was not intentionally investigated for this study, a sufficient understanding of self-efficacy as it relates to extracurricular participation was limited by the research design of this study. Future work should focus primarily of self-efficacy theory and measurement. A possible direction of this work would be to employ a mixed-methods study of students participating in extracurricular activities. A longitudinal study can then measure the extent of students' self-efficacy development due to participation in extracurricular engineering environments. A more intentionally comparative study could also be done to identify various curricular and non-curricular influences on students self-efficacy development. Qualitative and quantitative data can mixed to investigate whether self-efficacy develops as a result of extracurricular participation, or if students with pre-existing high self-efficacy are more likely to participate in extracurricular activities.

The types of represented extracurricular sites also limited this study, which was not an exhaustive list of the potential extracurricular opportunities available to engineering students. Future work should consider a comparative analysis and assessment of various extracurricular opportunities available to engineering students. In addition to the opportunities represented in this study, other engineering-related opportunities such as summer internships, co-ops, professional societies, and informal engineering clubs should also be considered. Additionally, the influence of other extracurricular participation on engineering students' educational experiences, including non-engineering-related student organizations, such as musical ensembles, Greek life, sports clubs, hobby groups, religious organizations, and student employment should also be considered. A comparative analysis can help identify the magnitude of influence different organizations might have on engineering students' educational experiences. Studies that identify the tangible impacts of extracurricular participation can provide necessary implications and recommendations towards reward systems for students heavily involved in extracurricular activities, while avoiding penalizing students incapable of committing to extracurricular activities (e.g. students with financial concerns, students on academic scholarships, etc.)

A key participating member not included in this study are the faculty or professional advisors that mentor and facilitate students in these extracurricular organizations. Future work should consider identifying the salient characteristics of faculty members who choose to facilitate extracurricular student groups. Additionally, future work should consider shedding light on the faculty experience within extracurricular organizations, from the perspective of the participating faculty. Future work could also help uncover the institutional affordances and barriers that faculty come across when choosing to advise or facilitate a student organization. This could help shed light on what faculty might consider to be a valuable use of time and resources, as well as how faculty translate their expertise to manageable application-based opportunities for students, and could help inform how to best shape recommendations for faculty interested in participating in extracurricular student groups.

6.2 Profile of a Student Participating in Extracurricular Engineering Groups

In closing, I would like to present a profile of a typical student participating in extracurricular engineering groups. In spending time with these students and extracurricular groups I have found that these students are in danger of being institutionally invisible, with their extracurricular achievements being overlooked and overshadowed by their curricular profiles. The following is a generalized profile of a student that is strongly committed to participating in extracurricular engineering groups, informed by the students I encountered during this study.

- Goal/task oriented when objectives autonomously defined
    - Self-driven to complete tasks
    - Self-driven to accomplish goals
- Self-seeks knowledge
    - Unconsciously or consciously reflective of current state of knowledge/skills
    - Identifies gaps in knowledge/skills and finds way to gain that knowledge/skill
- Practical
    - Struggles to reconcile accomplishing given tasks for the sake of completing a task
    - Values abstract accomplishments (e.g. grades) less than tangible accomplishments (e.g. implementing a design with a defined practical purpose)
- Dependent on peers
    - Accomplishes tasks/goals for the benefit of team/group
    - Learn from peers
    - Develop a community with peers
- Dependent on mentors
    - Knowledge/skill leaps are facilitated by experienced mentors
    - Validation of experience
- Experienced
    - Exposed to practical applications of knowledge/skills
    - Aware of realities that influence engineering work
- Self-aware
    - Exposed to what they truly know and what they truly do not know
    - Exposed of capability to "learn as you go"
    - Exposed to future possibilities and reflective (consciously or unconsciously) of future goals

Generally speaking, I have found that students participating in (and strongly committed to) extracurricular engineering groups are self-driven, dedicated, and passionate hard workers. These students had little tolerance towards their curricular demands, but valued certain elements that were particularly pertinent to their extracurricular work or other personal interests. Despite enjoying certain classes, however, these students were not strongly motivated "to get the grade".

Rather, they were more inclined to value understanding pertinent content and its application. *To these students, academic success in the traditional sense is not indicative of their abilities or identities as engineers. Achievements in their extracurricular pursuits, including how close peers and mentors viewed them, are the real reflections of their abilities and identities as engineers.*

It is important to keep in mind that this is a generalization of the students I encountered during this study. Considering the important reality that all students are individuals with unique traits and behaviors, it is important to note that the students I encountered exhibited either all or only some of the traits listed above. Some of the students that I encountered were very successful in terms of traditional academic merits of success. Some were clearly natural leaders, while others were more successful working in an environment with scaffolding (peer or faculty scaffolding).

Although generalized, this profile does help identify the salient features of engineering students participating in extracurricular engineering activities. This can further inform future studies geared towards identifying the types of students most likely to join extracurricular groups, as well as studies geared towards increasing inclusivity in extracurricular engineering groups. More imminently, I believe these traits should be closely examined as we begin to consider possible approaches to recognizing and rewarding students who commit much of their time as students towards valuable extracurricular work.

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Observation Name:
Date (Time):
Location:

APPENDIX A: OBSERVATION PROTOCOL

Observed Self-Directed Learner Autonomy:

Willingness	Motivation	
	Confidence	
Ability	Knowledge	
	Skills	

Observation Name:
Date (Time):
Location:

Observed Navigational Flexibility:

Goals/Interests	
Horizons of Observation	
Critical transitions	