Experiential Learning in Co-Curricular Settings:
What are the Professional Implications for Biomedical Engineering Students?

by

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ABSTRACT

Biomedical engineering (BME) undergraduate students take courses that allow them to develop skills in multiple disciplinary areas (e.g., biology, medicine, chemical, mechanical, electrical engineering) and as such, have a wide array of career opportunities available to them upon graduation. While their broad curricular exposure lends itself to flexibility in careers, it leaves little room in the curriculum for professional competence development and has been implicated in graduates' difficulties navigating career searches upon graduation. This research addresses this concern by examining how students enrolled in an BME program in a highly selective research university fill the professional development curricular gap while pursuing their undergraduate degree.

I leveraged professional development educational literature that described concepts of student involvement and experiential learning. These concepts emphasize the importance of active engagement to promote students' learning and development. Through in-depth analysis of the engineering education literature using a systematic search and qualitative synthesis of 100 full articles, I found that assessment efforts in experiential learning settings have largely focused on in-class opportunities and infrequently leverage mixed or qualitative methods of inquiry. This review of the literature informed my year-long qualitative study of BME students' professional development in out-of-class, co-curricular settings.

Each of the studies presented in this dissertation analyze data from a series of four interviews with fourteen third-year BME undergraduate students over one academic year. The studies focused on understanding relevant professional development questions for students pursuing BME degrees and engaging in co-curricular opportunities while pursuing their degrees. I found that BME students were most

frequently motivated to participate in co-curricular opportunities that they thought had value for their future careers, but also engaged in co-curricular experiences that supported parts of their identities or were generally interesting to them. I also found that BME students described their motivations for pursuing BME in similar ways. Participants in this study discussed personal interests as a motivating factor for pursuing a BME degree, and were able to articulate professionally relevant skills they described as unique to BME graduates. Furthermore, I found data that supports previously anecdotal disciplinary discussions about the career search and exploration process of BME students, finding that across the span of one year, students were discovering multiple new career options, and considering how to address perceived career placement difficulties after completing a BME degree. In my final analysis, I examined the data for evidence of participants' professional competency development over time, looking for patterns in the experiential process by which students developed professional competencies. I found evidence of learning processes connected to the development of ten professional competencies: business, career direction, communication, cultural, design, disciplinary, interdisciplinary, leadership, personal attributes, and teamwork.

My work can inform efforts to improve the previously understudied career search experiences of BME undergraduate students. The results of my work indicate the importance of career exploration opportunities throughout students' four-year experience in both curricular and co-curricular settings. My work also has implications for BME educators and advisors interested in co-curricular or experiential learning opportunities. Using the results of my final study as a basis, I have developed a set of recommendations for students interested in selecting co-curricular experiences that support specific professional competence development. Similarly, I recommended curricular strategies educators can incorporate in their classes to support the development of professional competencies linked to experiential, co-curricular engagement in my study.

CHAPTER I

Introduction: Setting Up the Study

This dissertation explores the professionally relevant experiences of undergraduate biomedical engineering (BME) students as they engage with co-curricular opportunities and learn through their bachelor's degree program. Historically, BME students struggle with career exploration and placement due to their broad degree experiences, multiple career options, and limited exposure to professional development opportunities in the traditional curriculum (Nocera et al., 2018; Ramo et al., 2019). In the following chapters I draw on student involvement and experiential learning theories to motivate my exploration of how BME students have come to understand how their curricular and co-curricular experiences inform their career interests and perspectives. I use data collected through interviews with 14 students during their third year of their undergraduate degrees, hearing from them how their coursework and co-curricular engagement influenced their professional trajectories and perspectives. My work provides considerations for faculty and staff who advise BME students' engagement and develop learning opportunities in BME degree programs. It also provides recommendations for students as they move through their bachelor's degree experience.

Study Motivation

Student engagement has frequently been studied as a predictor of college student learning and development (Mayhew et al., 2016). The study of engagement in college settings originated with concepts like Astin's (1984) model of involvement and Pace's (1998) research on a related concept he called quality of effort. Both these scholars' ideas suggested that more time and energy devoted to the academic experience by a student would lead to increases in learning. To Astin, involvement meant an investment of physical and psychological energy towards an experience, and that energy could occur on a continuum. Furthermore this energy has both quantitative (e.g. time on task) and qualitative (e.g. useful study strategies) features (Astin, 1984).

Scholars like Kolb have similarly studied learning related to engagement, exploring a concept called experiential learning (A. Y. Kolb & Kolb, 2008; D. A. Kolb, 1984, 2015; David A. Kolb et al., 2011). Experiential learning (EL) focuses on learning through doing, or the process through which learning occurs, and commonly describes four stages through which a learner moves (i.e., concrete experience, reflective observation, abstract conceptualization, and active experimentation) through a learning experience.

Throughout the learning literature, scholars have emphasized the importance of engagement and experience for students' learning, both through conceptualizations in line with Astin's (1984) and Pace's (1998) descriptions of involvement (Kuh, 2001, 2009) and through Kolb's (2011) description of EL (Cantor, 1995; Conger et al., 2010; Duderstadt, 2008; Harrisberger, 1976; Itin, 1999).

While engineering students can participate in EL both in the classroom and in co-curricular (out-of-class) spaces, professionally relevant learning has been strongly linked to experiences in co-curricular settings. Within engineering, co-curricular engagement has been linked to learning and development of professional competencies such as leadership, ethical decision making, teamwork, and communication (Burt et al., 2011; Busby, 2015; Fiorini et al., 2014; Fisher et al., 2017; Litchfield et al., 2016; Young et al., 2015). A recent review of the potential relationships between specific co-curricular opportunities and potential engineering student competencies suggests relationships between twenty competencies and twenty-two types of co-curricular experience (Fisher et al., 2017). The researchers suggest that research on the developmental benefits of co-curricular experiences for students has also prompted more institutions to encourage student participation in co-curricular activites and experiences (Busby, 2015; Conger et al., 2010). My dissertation explores what is known about professional learning through involvement and engagement in co-curricular settings, expanding on our current understanding that certain co-curricular experience types can lead to a subset of professional competency outcomes. To do this, I studied the learning that occur within co-curricular experiences to draw conclusions about what elements of those experiences are professionally meaningful or motivating.

I designed these studies to explore the BME undergraduate context because BME students frequently discuss difficulties navigating professional interests and careers upon graduation (Berglund, 2015a), making the professional development experiences of BME students an important area of study. Furthermore, co-curricular experiences play an important role in the BME undergraduate experience. The experiences and skills targeted within a BME curriculum can vary substantially from program to program based on the resources and strengths of the college or university, the BME department and its faculty's research (White et al., 2020). The varied BME student experience has become a common feature of the BME discipline, but it has also been linked to struggles students encounter when transitioning from an engineering student role to an engineering professional role (Nocera et al., 2018). In some spaces, BME undergraduate students have explicitly stated that they consider co-curriculars to be a key part of their preparation for professional careers (Berglund, 2015b). By exploring professional development within the context of BME and focusing on developmental experiences in co-curricular settings, we can begin to understand 1) how BME students develop professionally and 2) what is important and impactful about their co-curricular experiences for that professional development.

Research Objectives

My goal was to better understand students' professional development experiences within BME. Drawing on the literature that emphasizes the importance of student involvement and EL, I focused on exploring how participants connected their experiential, co-curricular engagement to their professional development. To do this, I first performed a literature review on how EL has been studied within engineering which identified a need to perform EL research in engineering that employs more measures and established education research methods, considers the benefits of qualitative and mixed methods study designs and explores EL in co-curricular contexts (C. S. E. Jamison et al., 2022). I subsequently designed four qualitative studies:

Study 1: Why do BME students participate in one or more co-curricular experiences?

Study 2: How do BME students describe their career interests and perceived job prospects in relation to why they pursue a BME degree?

Study 3: What do BME students perceive as possible careers in their field? How might their views changeover time?

Study 4: What are common elements across co-curricular experiences that students link to their development of professional competencies?

Overall Study Context

The studies presented in this dissertation all draw on the same longitudinal, interview-based data set. The students recruited for my project were each participating in at least one co-curricular and enrolled in a BME program at a large, R1 university in the Midwest United States. Students were entering their third-year at the start of the study and actively participating in at least one of two co-curricular experiences commonly available to students in research universities (i.e., a multidisciplinary design experience or directed research) at the time of recruitment. Overall, the project incorporates perspectives from fourteen participants. Eleven self-identified as female and three as male. Participants described their race/ethnicity in the following ways six Asian, two Hispanic/Latin(x), six White/Caucasian. During the interviews, three participants engaged in the multidisciplinary design experience (MDE) only, seven in research only, and four in both. Based on our own categorization, three participants had a low-level of engagement, six were considered to have mid-level engagement, and three had high-level engagement.

The MDE student group was engaging in a design project that addressed healthcare problems by supporting interdisciplinary, global health work through design and entrepreneurship strategies. Approximately half of the MDE students participating at the time of this study were BME majors. Multiple forms of engagement were available to students in the MDE: as a design incubator participant, on a design team, on a travel team, or as a board member. Several directed research opportunities existed for students, including pursuing research through independent study credit, hourly pay, or volunteering on faculty research projects. Student experiences related to the tasks they performed or the level of input they had in project decisions varied from lab to lab. During the interviews, I asked students to discuss their professional development through other co-curricular opportunities in which they had participated during the timeframe of the interviews. Students also named common experiences that included other professionally focused BME organizations: cooperative education and internship experiences, and other volunteer or outreach work.

At the time of my study (academic year 2019-2020), the BME program enrolled approximately 400 students (~56% identified as female and ~16% held a historically marginalized racial or ethnic identity in engineering). Since performing the study, the three-concentration curricular structure of the BME program has changed; however, the students in my study completed degrees in one of three concentrations: bioelectrical (~11% of graduates), biochemical (~58% of graduates), or biomechanical (~31% of graduates). A recent alumni survey indicates that approximately 26% of the program's bachelor's degree graduates enroll in medical school, 45% go into industry or government jobs, and 29% pursue other career pathways available to BME graduates (e.g., consulting, other post-secondary programs, etc.).

Participants were asked to participate in four interviews lasting between 45 and 90 minutes each interview over the course of the 2019-2020 academic year, including the summer. The first interview took place at the beginning of the 2019 fall semester, the second interview at the end of the 2019 semester, the third interview at the end of the 2020 winter semester, and the fourth interview before the start of the 2020 fall semester. Interviews focused on students' professional development experiences through the co-curriculars of interest, but also asked questions about the impact of their coursework and other co-curricular involvement on professional development.

I used both inductive and deductive coding approaches to data analyses based on the goals of each study (Hesse-Biber & Leavy, 2017; Hsieh & Shannon, 2005). In qualitative research, coding refers to a process of assigning a word or short phrase to a section of data to summarize or capture important attributes of that data (Saldana, 2016a). A deductive approach to coding uses established codes that the researcher expects to find in the data and explores the dataset for evidence of those codes. In study one, deductive coding was used to look at motivations for participating in co-curriculars through the lens of subjective task value constructs. In study four, the professional competence outcomes explored were informed by a review of engineering education literature on professional outcomes for engineers. Both of these coding schemes are described in the following Definition of Terms section. The remainder of the data analysis employed inductive approaches to coding. Inductive coding looks at the dataset for patterns, creating codes that describe the data and align with the research questions. Often, these codes can then be organized into categories or themes which can inform the overall research questions being asked. In studies two and three codes were organized into categories and themes to understand the career exploration experiences of BME students during their third year.

Definition of Terms

The following terms are defined here to help the reader understand the context of each term in this study.

Experiential Learning (EL): This term often describes a process of learning through doing. In my studies, I focused on the four stage process described by Kolb (A. Y. Kolb & Kolb, 2008; D. A. Kolb, 1984, 2015; David A. Kolb et al., 2011), though my work was also informed by other scholars who have described similar process-driven models (Itin, 1999). In Kolb's model, there are four connected stages through which a learner participates (has an experience), reflects (thinks about the experience they just had), conceptualizes (comes to understand what they just experienced in relation to what they already know), and then applies (tries again using what they just learned in a similar setting. Kolb terms these stages concrete experiences (CE), reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE), respectively (David A. Kolb et al., 2011).

Co-curricular: Simmons and co-authors (2017) described a co-curricular experience as an activity students participate in that can complement their curricular learning. In some instances, it can bear course credit (e.g., directed research credit, co-op credit, or credit for participating on a design team), but it does not need to be tied to a specific course or bear course credit. Similarly, Fisher and colleagues (2017) propose a broad categorization of co-curriculars as “activities administratively tied to a student’s undergraduate academic experience or educational institution but not required as a milestone to graduation (p. 287).” I used Simmons’ definition so I could examine internships or research experiences participants described during their summer experiences that were not administratively tied to the university.

Professional Competencies: In this work, I explored a broad range of professionally relevant student outcomes that I call professional competencies. The term ‘competencies’ includes students’ possession of both relevant knowledge (e.g., conceptual disciplinary knowledge) and skills (e.g., teamworking, communication) for the professional working world. In the last study of my dissertation, I present a literature review that identified categories of competencies discussed in BME, co-curricular, and curricular engineering contexts (Fisher et al., 2017; Passow & Passow, 2017; Denise R. Simmons et al., 2017; White et al., 2020; Woodcock, 2019). The categories included business competence, career direction outcomes, college outcomes, communication competence, cultural competence, data competence, design competence, disciplinary competence, ethics competence, interdisciplinary competence, teamwork competence, personal attributes outcomes, and leadership competence (see Table 21 for further categorization).

Subjective Task Value Constructs: In Chapter 3, I also use the subjective task value construct described in Eccles’ expectancy value theory (EVT) of achievement and motivation to explore how BME students value co-curricular experiences (Eccles, 2005). EVT aims to explain how individuals make choices based on their expected outcomes and the value they place on those outcomes (Wigfield & Eccles, 2000). In Subjective Task Value, there are four values dimensions:

1. Attainment Value: A task provides a way to confirm or support an aspect of how one sees oneself.
2. Interest Value: A task that individual enjoys or expects to enjoy doing.
3. Utility Value: A task perceived to benefit future plans.
4. Cost Value: A task can also have perceived cost(s) associated with performing the task.

Chapter Overviews

This section provides a general overview of the layout of my dissertation and adds details on each of the chapters.

Chapter 2 provides justification for why this project is important by exploring how EL has been studied in engineering previously. Findings indicate a need for more exploration of co-curricular settings, limited studies that explore development through qualitative means, and few studies that examine what elements of EL opportunities support student development.

Chapter 3 details the study performed using the first set of interviews with the participants of this dissertation. It explores students' motivations for participation in co-curricular settings finding that students have motivations that span across the four dimensions of subjective tasks values described by Eccles (2005) in their Subjective Task Value framework. Findings indicated that utility values were the most commonly described and often related to motivations to address the perceived difficulties of getting a job upon graduation. Participants in MDE more often describes attainment value motivations and research participants more often described interest values. Cost values were infrequently discussed.

Chapter 4 similarly explores participants' motivations, but rather than focusing on their participation in co-curricular settings, it explores their motivations for pursuing a BME degree. Career exploration and aspiration discussions were extracted from the first three interviews of the dataset for the analysis. Findings of this study demonstrate motivations for pursuing a BME degree beyond the professional implications attaining a degree has, career-relevant skills participants perceive as unique to BME graduates, and career-placement tradeoffs associated with BME bachelor's degree attainment.

Chapter 5 then examines what students perceive as possible careers in the BME field and where they find that information. It also pulls from data generated from interview questions about career exploration and aspirations in the first three interviews. Results indicate that students' perception of possible careers continue to expand across the span of their third academic year, that students have varied degrees of certainty regarding what path or paths they wish to pursue, and that they place value on opportunities to discover and explore the broad range of careers available to them through BME.

Chapter 6 combines the BME and co-curricular contexts and aims to identify elements of co-curricular EL opportunities that lead to development of career-relevant professional competencies. Through the analytical approach used, I connected students' discussions of their experiences to ten professional competencies (business, career direction, communication, cultural, design, disciplinary, interdisciplinary, leadership, personal attributes, and teamwork). Common elements of experience that participants connected to their development included Independent Project Work, Project Work That Engages Multiple Disciplines, STEM Education Opportunities, and Mentorship From a Skilled Other. I also found that a common action participants connected to their competency development was their Reflection on Experience.

Chapter 7 provides a discussion across the four studies included in this dissertation to make connections across findings.

Chapter 8 adds a summary of the implications this work has for future research and BME educational practice and details goals for my future research in this space.

CHAPTER II

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Background: Experiential Learning Implementation in Undergraduate Engineering Education

Abstract**.** Experiential learning (EL) is a process of learning through doing, while experiential education incorporates the pedagogies and structures that support this process. As the benefits of EL have become more evident, experiential engineering education (EEE) efforts like design courses, have increasingly been integrated into undergraduate curricula. However, few efforts have examined the research approaches used to determine the impact of EEE on student learning outcomes. This review examines how EL has been implemented and evaluated in previous undergraduate engineering education publications by performing a systematic search and critical review of relevant articles. Results indicate that a majority of articles study EL and education within the context of one course and employ course evaluation methods in line with goals of the Scholarship of Teaching and Learning research community. Suggestions for future research on EL and education that will allow for a broader understanding of its impact in engineering education are provided.

Introduction

Experiential learning (EL), frequently understood as learning by doing, focuses on the process through which a learner comes to understand something new. Experiential learning as a concept in higher education is often credited to David Kolb (A. Y. Kolb & Kolb, 2008; D. A. Kolb, 1984, 2015; David A. Kolb et al., 2011), though other scholars have created models to explain the EL process as well (Itin, 1999). Kolb describes his model of EL as a process involving four interconnected stages through which a learner participates (has an experience), reflects (thinks about the experience), conceptualizes (comes to understand what they experienced), and then applies (tries again in a similar setting) what they have learned through a given experience. Kolb's model, along with other scholars' models that aimed to describe the EL process, is broadly applicable for understanding multiple EL settings and pedagogies. As such, EL models have been used to guide the implementation and assessment of EL in multiple educational settings and many scholars believe that experiential education, the structured effort by educators to facilitate EL, is beneficial for students' learning (Cantor, 1995; Conger et al., 2010; Duderstadt, 2008; Harrisberger, 1976; Itin, 1999).

In recent years, likely due to the emphasis placed on how experiential education can add value to the student experience by improving learning outcomes in undergraduate engineering education (Graham, 2018), there has been an increase in studies examining EL outcomes within higher education-specific opportunities (i.e., as part of the curriculum or in an extra-curricular). However, multiple EL models have been applied across experiential education efforts in engineering. Inconsistency in how the models are applied in education efforts (e.g., what setting or pedagogy is used, what scholar's model if any is cited, or how learning is assessed) has made its overall impact in engineering education hard to interpret. Despite a limited understanding of the overall impact of EL opportunities in undergraduate engineering education, policies and global calls for experiential education in engineering continue to increase (Graham, 2018; *Infusing Real World Experiences into Engineering Education*, 2012; National Academy of Engineering, 2005; The Royal Academy of Engineering, 2007).

As such, this systematic literature review was performed to address the need to understand the impact of EL opportunities in undergraduate engineering education more comprehensively. The purpose of this review is to establish a foundational understanding of current approaches to research on experiential engineering education (EEE) implementation and assessment. A discussion of current experiential education contexts and their corresponding assessment strategies and limitations are presented.

Further, this study contributes to the literature on EEE by providing recommendations for future research. These recommendations will improve transferability of student learning outcome findings and increase the comprehensive understanding of the impact of EL opportunities in engineering education.

Background

EL, a concept first reflected in writings by John Dewey, is often described as 'learning by doing' (Dewey, 1916). Models of the EL process explain outcomes of the process as a change in judgement, feeling, knowledge, or skills as a result of living through an event or events (Itin, 1999). Many of the models that describe the EL process have similar features. A review of EL models found that many of the models describe a four stage cyclical process that generally follow the same pattern (i.e. action that creates an experience, reflection on the action and experience, abstraction drawn from reflection, and application of the abstraction to a new experience or action) (Itin, 1999). Kolb's model of the EL process aligns with the four stages described in that review, and is perhaps the most referenced conceptualization today (A. Y. Kolb & Kolb, 2008; D. A. Kolb, 1984, 2015; David A. Kolb et al., 2011). Kolb's model describes learning as a process where "knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience (D. A. Kolb, 1984)". In his model, learners move through four interconnected stages: concrete experiences (CE), reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE) (David A. Kolb et al., 2011).The interconnectedness of the four stages state that the immediate experience (CE) serves as a basis for a learners observations and reflections (RO) which can then be assimilated by the learner into a new conceptualization of a topic (AC) and applied to a new or similar situation in the future (AE) (D. A. Kolb, 1984).

Crediting the development of the model to the work of scholars Kurt Lewin, John Dewey, Jean Piaget, and others, Kolb's model was developed as a framework that can incorporate the learning process views of multiple scholars and serves as a tool for research on and evaluation of EL across learning contexts (e.g., curricular, co-curricular, informal learning) (A. Y. Kolb & Kolb, 2008; D. A. Kolb, 2015). Kolb integrated the work of these scholars by incorporating six of the scholars' overlapping perceptions of learning into his description of the EL process:

1. Learning is best conceived as a process, not in terms of outcomes.
2. All learning is re-learning.
3. Learning requires the resolution of conflicts between dialectically opposed modes of adaptation to the world.
4. Learning is a holistic process of adaptation.
5. Learning results from synergetic transactions between the person and the environment.
6. Learning is the process of creating knowledge.

Since publication, Kolb's model has been applied in multiple higher education contexts (e.g., management, education, information science, psychology, medicine, nursing, accounting, law, etc.), to develop educational opportunities and to perform research and evaluation on educational practice (D. A. Kolb, 2015). Despite its wide use, Kolb's model is not without critique. Some scholars wishing to apply this model have argued that the term concrete experience is unclear and has led to varied interpretations of the term by researchers and educators alike (Morris, 2019).

Experiential education, or the formal structures implemented to guide a learner through an EL process, is frequently defined in ways that make distinguishing differences between experiential education and EL difficult. The similarity in definitions of EL and experiential education further complicate how educators use models of EL to develop educational opportunities. As an example of the minimal distinction between definitions of experiential education and EL, in 1994, the Association for Experiential Education defined experiential education as "a process through which a learner constructs knowledge, skill and value from direct experience" (quoted from (Itin, 1999)). This definition describes a process which aligns it strongly with definitions of EL; however, it does not address the structures or pedagogies used to implement the learning which would more clearly distinguish the two terms. Vague and overlapping definitions of the two concepts (EL and experiential education) have led to efforts to more clearly define what experiential education is and what it looks like in practice (Itin, 1999; Luckmann, 1996). These newer efforts to describe what experiential education looks like in practice acknowledge that EL models could be applied in multiple educational settings (e.g., classrooms, service learning experiences, study abroad, design teams, etc.) in many ways, and as such, new definitions describing what experiential education entails are still quite broad. Common structures and pedagogies of an experiential education setting were identified by synthesizing similarities across newer and more distinct definitions of experiential education. They include opportunities for students to interact with the teacher, take risks and make mistakes, and reflect on the experience (Itin, 1999; Luckmann, 1996).

Whether described as EL or experiential education, the emphasis on learning through experience has been consistently present in higher education contexts over the past several years (Itin, 1999). This emphasis may stem, at least in part, from faculty's desire to better serve students by improving career placement, improving underrepresented student retention, and improving learning outcomes (Cantor, 1995). Experiential education is thought to improve students' chances to enter their preferred profession which has become a concern for many students due to increasing competition among graduates for positions that require a bachelor's degree (Cantor, 1995). Experiential education has also been recognized for encouraging positive recruitment and retention metrics for underrepresented student populations among other student-driven reasons for incorporating EL opportunities (Cantor, 1995). As EL opportunities have become more widespread in higher education, their implementation has spanned a wide breadth of teaching approaches (e.g., field work experiences, internships, previous work experience, outdoor education, adventure education, vocational education, lab work, simulations, games, inquiry-based learning, student-directed learning, active learning, problem-based learning, service learning, project-based learning etc.) (Itin, 1999; Morris, 2019). This vast array of possible applications for EL in education efforts has made conversations about high quality implementation and evaluation of these efforts complex.

In engineering, EL opportunities have also become highly valued, particularly at the undergraduate level. Discussions of its importance date back to the 1970's (Harrisberger, 1976). Calls similar to those by Duderstadt (2008) saying, "… it is long past time that we ripped engineering education out of the lecture hall and place it instead in the discovery environment of the laboratory, the design studio, or the experiential environment of practice" (Conger et al., 2010, p. 2) and the American Society of Engineering Education Cooperative Education Division's name change to Cooperative and Experiential Education Division (CEED) in 2009, indicate an increased emphasis on EL opportunities by engineering educators. Similarly, global reports on undergraduate engineering education indicate a desire to increase experiential education in engineering (Graham, 2018; *Infusing Real World Experiences into Engineering Education*, 2012; National Academy of Engineering, 2005; The Royal Academy of Engineering, 2007). This emphasis is not surprising considering the alignment between goals of experiential education and engineering design efforts that aim to give students realistic experiences with engineering design within the undergraduate experience (Harrisberger, 1976). Educators also believe that EL opportunities at the undergraduate level can help produce more innovative engineers who are better prepared to enter and contribute to the engineering workforce (Conger et al., 2010).

Despite the value placed on experiential education in undergraduate engineering contexts, there are minimal investigations of the impact of EL across educational contexts (e.g., curricular, co-curricular, etc.). Some researchers have aimed to begin this work by examining the impact of EL in one educational context (e.g. out-of-class involvement (B. Johnson & Main, 2020), community service in engineering (Chan, 2012a)), but the narrow scope of these studies limits the insights that can be drawn about the overall impact of EL in engineering education broadly. In their reviews of EL, Chan (Chan, 2012a) and Johnson and Main (B. Johnson & Main, 2020) focused their studies by looking at a specific educational context in which EL might take place. Chan examined EL opportunities in engineering through service learning contexts (Chan, 2012a) while Johnson and Main focused on EL that took place through out of class involvement (B. Johnson & Main, 2020). Both reviews report that development and evaluation of experiential education in engineering needs further clarification and calibration. Additionally, both research teams call for further research to better understand the mechanisms and extent of impact of EL opportunities for engineering students. While reviews on EL within a specific engineering education context can contribute to calls for a better understanding of how to develop opportunities and assess the impact of EL, reviews that examine assessment approaches across educational contexts are still needed.

In an effort to clarify how EL models are applied to develop opportunities and assess the impact of EL in higher education beyond engineering contexts, one review aimed to better understand the theory behind Kolb's EL model (Morris, 2019). In their recent 2019 study, Morris performed a review to understand how the term 'concrete experience' was understood and operationalized by researchers who applied Kolb's EL model. The study resulted in proposed revisions to all four stages of Kolb's model that more specifically define what the process looks like. Morris defined each stage in the process model based on Kolb's original model, but added clarifying terms to each stage. The new model included four stages named *contextually rich* concrete experience, *critical* reflective observation, *context-specific* abstract conceptualization, and *pragmatic* active experimentation (*italics* indicate added terminology). These revisions aimed to give researchers and educators a more explicit idea of what sorts of experience, reflection, conceptualization, and experimentation align with the EL process (Morris, 2019). As a relatively new contribution to the literature, Morris' review may help educators determine how to develop pedagogy or other educational initiatives (i.e., out-of-class opportunities) that facilitate EL. The findings of this work could inform how educators develop EL opportunities that align with theoretical models of the EL process moving forward, but it did not address how to assess or determine possible student outcomes of EL opportunities.

This study seeks to contribute to engineering educators' implementation and evaluation of experiential education using a systematic, intentionally broad review of EL in engineering undergraduate education. Global engineering education reports continue to call for the implementation of EL opportunities at the undergraduate level (Graham, 2018; *Infusing Real World Experiences into Engineering Education*, 2012; National Academy of Engineering, 2005; The Royal Academy of Engineering, 2007). However, these calls have not considered how EEE opportunities have been assessed or evaluated in relation to student development. More research is needed to understand how current research assesses the benefits of EL opportunities in engineering to create a shared understanding of best practices for implementation and evaluation. Therefore, this paper examines the evaluation methods and contexts in which EL has been implemented, rather than identifying the student outcomes of the EL. By examining the range of educational contexts in which EL opportunities exist as well as their corresponding evaluation efforts, this review will contribute a discussion of current exemplar evaluation strategies, limitations of research in undergraduate EEE, and provide recommendations for evaluation and assessment in future works.

Study Design

Systematic reviews are often used to describe the state of knowledge or practice on a topic and identify opportunities for future research. This study follows pre-established methods for conducting a systematic search and critical review of literature on assessment and evaluation practices of EL in engineering higher education (Borrego et al., 2014; Grant & Booth, 2009). The study aims to establish a basic understanding of how and in what contexts EL has been assessed and evaluated currently and make recommendations for where more research is needed and how that research can be advanced.

Systematic Search. A systematic search aims to identify all relevant articles in a transparent, reproducible way, so that a subset of articles may then be selected for analysis and synthesis according to exclusion criteria (Borrego et al., 2014). In this study, three databases covering the two major research disciplines (engineering/science and education) relevant to the research question were searched: Elsevier's 'Scopus' (www.scopus.com) and Clarivate's 'Web of Science' for engineering/science literature and the education database 'Educational Resources Information Center' (ERIC) which is part of ProQuest (https://www.proquest.com/eric/index). Applying an iterative process that combined multiple search terms related to the research question to select the systematic search terms, the authors selected a set of search terms that allowed for a focused, but broad set of EEE articles to review that were clearly focused on assessing or evaluating learning in a higher education setting (Borrego et al., 2014). The same search criteria were used for all three databases on April 29, 2020, and fit the general format of: (“higher education” OR HEI [i.e., higher education institution]) AND (assessment OR outcomes OR evaluation) AND (“experiential learning” OR “problem-based learning” OR “project-based learning” OR “experiential education” OR “service learning”) in the title, abstract, or keywords. For the ERIC database, AND (engineer OR engineering) was added because it is primarily an education database. To further scope the articles relative to the research question, filter features were used in each database. Results were limited according to publication date, key word, and type of article. The search was limited to journal articles, conference articles (not proceedings), and review articles published in or after 2010. Key words that indicated pre-college (K-12) or online learning settings as well as curriculum development were also used to exclude articles because they did not align with the focus of this review. Distinctions between undergraduate and graduate population were evaluated as an inclusion criteria at the abstract review level because they were not effectively captured using the keyword scoping strategy.

The initial search resulted in a total of 2,501 citations without accounting for possible duplicates across databases. Scopus (n = 1,462) had the highest number of citations followed by ‘Web of Science’ (n = 648) and ERIC (n = 391). Borrego and colleagues recommend using other methods to identify additional articles such as citation searching, contacting experts, or hand searching if a sufficiently large number of articles are not identified with a database search (Borrego et al., 2014). In this study, these additional identification strategies were not used because the over 2,000 articles identified in the original search were interpreted by the research team as sufficient to explore the research questions posed. Limitations of this search approach and recommendations for an extension of the search performed in this study are included in the discussion. Using the Rayyan (https://www.rayyan.ai/) online literature review tool’s duplicate recognition feature (Ouzzani et al., 2016), a comparison of the three searches was performed which identified 241 duplicate entries. Duplicate entries were extracted leaving a final data set of 2,260 unique articles to be reviewed by the first two authors (see Figure 1 for details). Inclusion and exclusion criteria were then developed iteratively between the first two authors (see Table 1) to align articles with the following research questions:

How has EL for undergraduate students in engineering higher education been implemented and evaluated?

a. *What student populations are studied?*
b. *What educational settings are studied?*
c. *What assessment approaches are employed?*
d. *What EL strategies or settings are explored?*

The first two authors read through the 2,260 unique article abstracts assigning an ‘include’, ‘maybe’, or ‘exclude’ code in Rayyan (Ouzzani et al., 2016) based on the criteria in Table 1. A key inclusion criterion for this review was that EL opportunities included in the review should align with Kolb’s EL model. This criteria required abstract reviewers (the first two authors) to look for learning opportunities with features that could align with each of the four stages in Kolb’s model (i.e., concrete experience, reflective observation, abstract conceptualization, and active experimentation). Most frequently, the abstracts that aligned with the model and assigned ‘include’ were learning opportunities that allowed students to iterate or learn from part of an experience and try again. Recognizing the critiques of Kolb’s EL model in the literature, Kolb’s model was selected as a conceptualization of EL for this literature search because its broad inclusion criteria allowed for an examination of a wide variety of educational opportunities that can facilitate EL. While coding, ‘maybe’ was assigned to abstracts without enough detail about a given decision criteria (e.g., population, alignment with Kolb’s model, etc.) to clearly denote as ‘include’ or ‘exclude’. The first two authors then came together to discuss discrepancies (one reviewer indicates ‘include’ and the other ‘exclude’) in assigned codes (accounting for less than 5% of total abstracts reviewed). After discussion, a total of 111 articles with clear ‘include’ decisions from both of the first two authors were selected to be reviewed in full and coded for study population, study context, assessment method, and EL setting. Six (6) of the 111 articles selected for full review were unavailable for virtual access at the institution where this review was performed due to the 2020 COVID-19 pandemic (Callaway et al., 2020). An overview of the article selection process is depicted in Figure 1.

Table 1. Literature review inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Criteria 1 ✓ International or domestic journal articles, conference proceedings, critical literature reviews.	× Books, book chapters, dissertations, or book reviews.
Criteria 2 ✓ Empirical data collected from human participants.	× Studies without a specified research methods, assessment, or evaluation section.
Criteria 3 ✓ Initiative must have a goal to serve and examine the development of undergraduate engineering students.	× Studies that serve or examine the development of students not in an undergraduate engineering degree program (e.g., information systems, construction management, chemistry, biology, K-12 curriculum). × Studies that only describe environment, initiative, or pedagogical approach (e.g., a work in progress or update article) without results.
Criteria 4 ✓ Studies must evaluate, assess, or examine an experiential learning environment, initiative, or pedagogical approach[1].	× Studies that examine part of the environment, initiative, or pedagogical approach not exclusive to its experiential classification (e.g., a study describing a PBL pedagogy but assessing team dynamics). × Studies that provide anecdotal results without an evaluation plan of the experiential environment, initiative, or pedagogical approach described. × Studies that focus on the creation of a tool to aid experiential learning initiatives but do not implement the tool (e.g., usability testing).

Critical Review. While reviewing abstracts, the first author developed a set of preliminary codes to establish a coding rubric for analysis. The first two authors then analyzed ten (10) full articles to further develop the coding rubric. The rubric was designed to identify relevant implementation and evaluation details of EL opportunities, including the student populations and contexts studied, assessment strategies, and the type of EL setting. The first three authors then divided the remaining 95 articles to be reviewed individually. Full-article reviewers (the first three authors) met weekly to discuss the coding rubric and adjust the codes as needed. During the full-article review, five (5) articles were removed from the analysis pool because they met exclusion criteria that were not identified through the abstract review. One hundred (100) articles were included in the final article review process and synthesized for this review (see

[1] Experiential learning in this review is in line with the views of Kolb (D. A. Kolb, 1984). In general, participants should have the opportunity to 1) have an experience 2) reflect on that experience 3) abstract or synthesize that experience 4) plan or experiment based on what they learned.

Table A. 1). A supplemental spreadsheet documenting relevant details of each article has been included in this review (see Supplement 1 – available upon request).

Each article was characterized using four categories related to the research question: assessment method, context, EL setting, and study population. Table 2 shows the organization of codes that belong to each of the four categories used in this review. Definitions of the codes created for each of the categories (except context which only had two codes defined below) are included in Table 3 - Table 5. Articles could have multiple codes for the categories of EL setting and context. Articles were categorized by the method used to evaluate the EL setting and were coded as a *quantitative*, *qualitative*, or *mixed methods study*, *testimonial/opinion,* or as a *program/course evaluation* study. Many of the articles reviewed explored questions with respect to a specific program or course context, asking questions and collecting data to evaluate that unique experience rather than developing studies that employ education research methods more intentionally. In those instances, articles were deemed to be a *program/course evaluation* study if they did not clearly apply educational theories or methods in the article. Context was categorized in one of two ways, either as a *program/course*, or as a *co-curricular/extra-curricular*. Articles coded as *program/course* were conducted in either a classroom setting or were formally tied to a course or academic program. Articles coded as *co-curricular/extra-curricular* took place in an outside of class setting, such as undergraduate research or a project or build team not connected to a student's coursework. Study population was coded as *engineering college broadly*, *women engineering students*, *one discipline*, *compares engineering disciplines*, *multidisciplinary*, *first year engineering*, or *one course without major distinctions*. Finally, the authors coded the EL setting based on thirteen (13) codes (see Table 5 for codes and definitions). Multiple codes could be, and often were, used to describe the setting in a given study. In some cases, the use of a *problem (PBL), project (PjBL), or challenge-based (CBL) learning* pedagogy was the only distinguishing characteristic in an article that would indicate the presence of EL. Based on that, the *problem (PBL), project (PjBL), or challenge-based (CBL) learning* code was developed which frequently co-occurs with other EL setting codes that more cleanly describe the learning setting. After the initial coding of the papers, one member of the research team coded for demographics including: discipline, total n of study population, assessment topic (see Supplement 1 – available upon request). The presence of details like sex or gender, age or academic standing, and race or ethnicity of participants, as well as, assessment resources, experiential* or project or problem-based learning* in title were also recorded in Supplement 1 – available upon request. This explicit coding of demographics was performed to provide a comprehensive presentation of the dataset for interested readers.

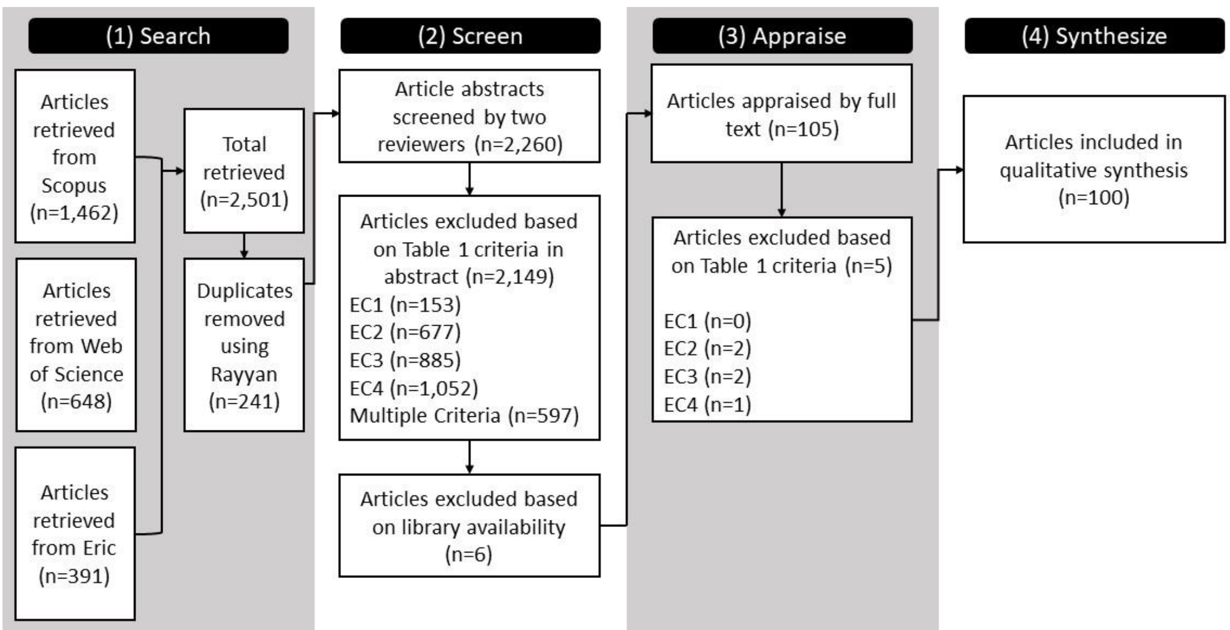

Figure 1. Flowchart for article review process adapted from (Borrego et al., 2014) description of the PRISMA statement by (Liberati et al., 2009).

Results

Demographics of the articles selected for full review (i.e., what types of articles and where they were published) are first presented. Then, results of the open-coding strategy used to explore this study's research question based on four categories (i.e., assessment method, context, EL setting, and study population) are presented. Overall, most of the articles addressed a specific course or curricular program, focused on students in *one discipline* or *one course without major distinctions* (Table 3), incorporated some aspect of *problem (PBL), project (PjBL), or challenge-based (CBL)* *learning* (Table 5), and evaluated the initiative using course evaluation strategies (Table 4).

Table 2. Categories and corresponding codes used to characterize articles included in the full review.

Category	Code
Assessment Method	*Mixed Methods Study*
	Program / Course Evaluation
	Qualitative Study
	Quantitative Study
	Testimonial / Opinion
Context	*Program / Course*
	Co-curricular / Extra-curricular
Study Population	*Compares Engineering Disciplines*
	Engineering College Broadly
	First Year Engineering
	Multidisciplinary
	One Course without Major Distinctions
	One Discipline
	Women Engineering Students
Experiential Learning Setting	*Collaborative Learning*
	Flipped Classroom
	Gamification
	Internship, Co-op, Site Visits
	Service Learning
	Laboratory
	Multidisciplinary Collaboration
	Problem (PBL), Project (PjBL), or Challenge-Based (CBL) Learning
	Project Teams
	Self-Directed Learning
	Study Abroad
	Summer Program
	Virtual/Augmented Reality

Demographics of Articles Reviewed. Articles were almost evenly distributed between journals (n=55) and conference proceedings (n=45) (Figure 2). There was a broad range of journals represented in this study. The most frequent journal publication channels used for the reviewed articles were IEEE Transactions in Education (12 articles), European Journal for Engineering Education (7 articles), Advances in Engineering Education (5 articles), and International Journal of Engineering Education

(4 articles). All other journals represented in the study had two or fewer articles. A total of nine (9) conferences were represented by the articles in this review. The conference with the highest number of articles in this study was the American Society of Engineering Education (ASEE) Annual Conference and Exposition which represented thirty-one (31) articles. The second highest number of conference articles came from the IEEE Frontiers in Education Annual Conference with five (5) articles. Only sixteen (16) articles included some variation of experience or experiential in the title, while thirty-seven (37) contained some variation of project or problem-based learning.

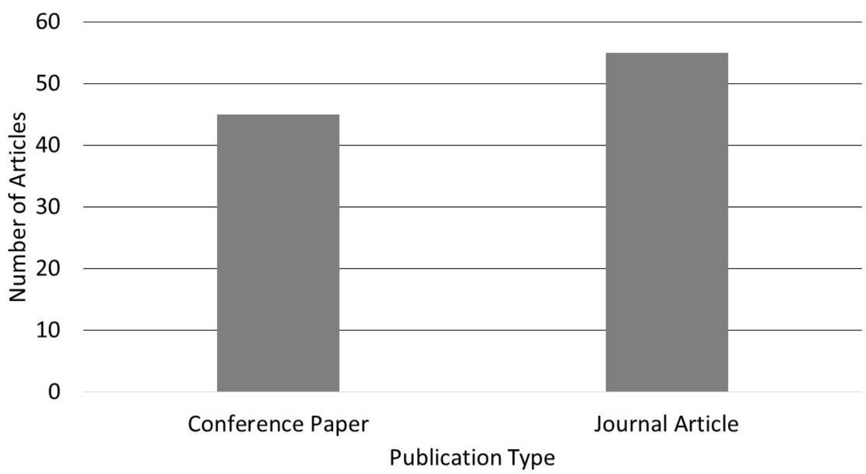

Figure 2. General publication trends of articles selected for full review. Articles are organized by type of publication, either journal article or conference article in a conference proceedings.

Study Population. Figure 3A illustrates the number of articles assigned a code for each of the eight study population codes. Of the eight study populations codes identified, the most frequently studied population was *one discipline*, as 55 of the articles in this review had sought to study EL in the context of one discipline or one course/program within one discipline. *One course without major distinctions* and *multidisciplinary* populations were also frequently (19 articles and 11 articles respectively) selected study populations. The majority of the articles were coded with only one study population code; however, four (4) articles were coded with two study populations as some of the populations were not mutually exclusive (e.g., at least one article studied *one discipline* but also looked at differences experienced by *women engineering students)*. In the four (4) articles that were assigned two study populations, co-occurrence of codes was between *one discipline* and *women engineering students* (2 articles) or *one discipline* and *one course without major distinctions* (2 articles). Definitions for how codes were defined can be found in Table 3.

Table 3. Study population codes and their definitions as applied in the full article review.

Code	Definition
Compares Engineering Disciplines	Focuses on experiences and development of engineering students in more than one discipline and explicitly compares between engineering disciplines in the analysis or discussion.
Engineering College Broadly	Impacts a majority of engineering students in either a small college or an engineering college and does not analyze data with regard to more specific population categories (see other codes in this category for examples). Is required for most or all engineering students.
First Year Engineering	Focuses on engineering students in their first year of engineering (could be before majors are declared or as a course required by all first year engineering students).
Multidisciplinary	Focuses on multiple disciplines or majors working towards a goal. Typically, is a small number of individuals where comparisons across disciplines is not the objective.
One Course without Major Distinctions	Focuses on one course of students, which may come from multiple engineering disciplines, but distinctions between students by major are not made.
One Discipline	Focuses on experiences and development of engineering students in the context of one discipline, disciplinary course, or program associated with one discipline. There may be more than one discipline represented in the student population studied but those differences are not compared.
Women Engineering Students	Focuses on experiences and development of women engineering students. Could compare to male students as well.

Study Context. The study context category (see Figure 3B) was coded to indicate if the article examined EL in a context linked to coursework or in a context outside of the curriculum. Results in this category provide information about how EL opportunities have been implemented to date. The articles fell into two different contexts: *course/program* (83 articles) and *co-curricular/extra-curricular* (21 articles). One study context code was assigned to a majority of the articles (96 articles), but a small number of articles examined initiatives that took place in both contexts and were coded with both study context codes (4 articles).

Assessment Method. The assessment method category was developed to understand how EL opportunities have been evaluated to date. The assessment method results demonstrated common methods for assessing EL opportunities as well methods that are less frequently used. Five (5) different assessment method codes were used in this review (see Table 4 for codes and definitions). The most commonly used assessment method was *program/course evaluation*, which was implemented in sixty-nine (69) articles. The remaining assessment methods were *quantitative study* (21 articles), *qualitative study* (9 articles), *mixed methods* (7 articles), and *testimonial/opinion* (2 articles). Figure 3C shows the frequencies of each of the codes. The majority of the articles were coded with only one assessment method code (92 articles), but the remaining eight (8) articles were assigned two different methods. These articles were assigned two methods because the main aim of the articles appeared to be assessment of learning outcomes, but in doing so were using established quantitative or qualitative research methods in their study design or analysis. Of the eight articles that were assigned two different methods, all eight (8) of them were classified as *program/course evaluations*, with five (5) of them additionally classified as also a *quantitative study* and the remaining three (3) as also a *qualitative study*.

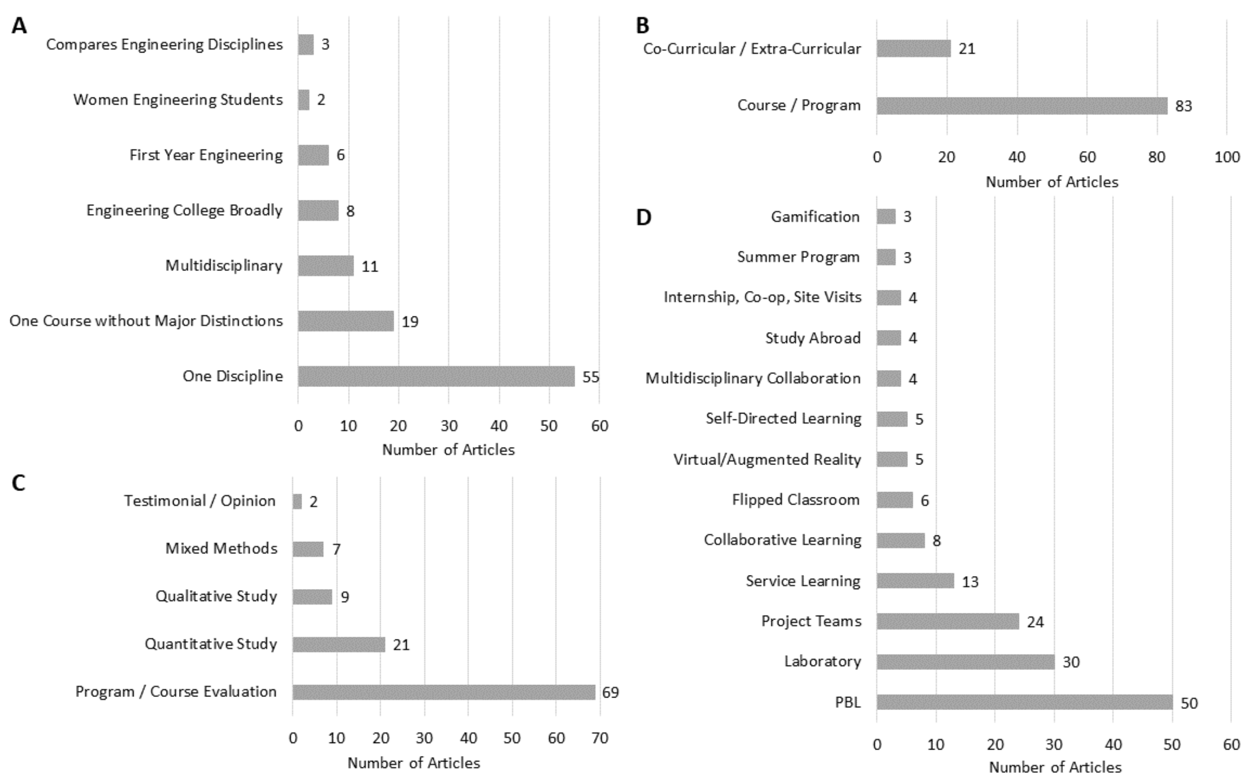

Figure 3. Coding results for (A) study population, assessment method, (B) study context, (C) assessment method, and (D) experiential learning setting categories.

Table 4. Assessment method codes and their definitions as applied in the full article review.

Code	Definition
Mixed Methods Study	Uses a combination of quantitative and qualitative measures and methods to assess development.

Program / Course Evaluation	Focuses on assessment of a program or course, typically seeking to assess growth in stated learning outcomes.
Qualitative Study	Uses only qualitative methods (e.g., open-ended survey questions, interviews, student artifacts) to assess development of participants. Methods are aligned with qualitative approaches.
Quantitative Study	Uses a previously established survey or other quantitative instrument to assess growth in participants (e.g., a pre- post- format) or implements an intervention within a course/program and measures impact (e.g., grades, test scores, etc.) of that intervention.
Testimonial / Opinion	No clear methods described, and the article does not assess development of students in a course or program. It may address satisfaction or perceived benefits.

Experiential Learning Setting. Similarly, results in the EL setting category provided information about how EL opportunities have been previously implemented. Articles frequently described EL opportunities that could be assigned multiple codes in this category. The frequencies for the 13 different EL setting codes are depicted in Figure 3D. As evident from the figure, the most commonly studied setting for EL was coded as *problem (PBL), project (PjBL), or challenge-based (CBL) learning* (defined in Table 5). The majority of the articles included in the study were assigned one EL setting code (64 articles); however, a significant number of articles were also assigned two EL setting codes (26 articles). Nine (9) articles were coded with three EL setting codes. One (1) article was assigned all 13 EL setting codes based on how it defined EL opportunities. A majority of the articles that were assigned multiple EL settings codes had co-occurrences between *problem (PBL), project (PjBL), or challenge-based (CBL) learning* and *laboratory* or *project teams*. Co-occurrences of *problem (PBL), project (PjBL), or challenge-based (CBL) learning* with *collaborative learning* and *self-directed learning* were also present. Overall, *problem (PBL), project (PjBL), or challenge-based (CBL) learning* appeared the most frequently in instances of co-occurrence in EL setting codes. Other smaller co-occurrences in EL setting codes were found between *project teams* and *laboratory, collaborative learning,* and *laboratory*, as well as *service learning* and *study abroad.* Table 6 demonstrates the co-occurrence patterns observed in the analysis.

Table 5. Experiential learning setting codes and their definitions as applied in the full article review.

Code	**Definition**
Collaborative Learning	Incorporates a setting where students work as a collective (e.g., a full student org or a full class) to complete tasks. Often they provide feedback to improve another's work. This can also include peer or near-peer tutoring.
Flipped Classroom	Applies a flipped classroom approach (often explicitly named) where the instructor facilitates activities, potentially ones previously assigned as homework, during class

	time. Out of class work may include: watching online lectures, participating in online discussions, or researching at home.
Gamification	Applies game design and elements of gaming experiences to the creation of the learning environment.
Internship, Co-op, Site Visits	Allows students to participate in a 'real-world' / professional setting.
Service Learning	Focuses on community outreach or service (can be domestic or abroad) or is described as service learning in the article.
Laboratory	Is in a lab setting. The lab could be focused on electronics or software, wet lab experiments, etc. This also includes undergraduate research work.
Multidisciplinary Collaboration	Engages students from multiple disciplines to perform the tasks/work associated with the initiative as a key element of the experience.
Problem (PBL), Project (PjBL), or Challenge-Based (CBL) Learning	Applies PBL (solving a problem), PBjL (completing a project), CBL (addressing a real-world ‘challenge’ or ‘problem’) pedagogical strategies as a key element of the design of the learning environment. May also be described as active learning.
Project Teams	Incorporates design projects completed in teams. Projects could be part of a design course (teams stay the same throughout the course) or part of a co-curricular society/group/competition (e.g. Formula SAE, ChemE Car, etc.)
Self-Directed Learning	Requires students to reflect on their own development and make decisions on how to improve as a key element of the experience.
Study Abroad	Incorporates experience abroad as a key element of the experience.
Summer Program	An immersive program that takes place over a short period of time typically in the summer.
Virtual/Augmented Reality	Incorporates technologies like virtual or augmented realities, or simulations to improve the learning environment.

Table 6. Co-occurrence patterns observed for codes assigned for experiential learning setting. Co-occurrences with frequencies above 2 are bolded.

	Collaborative Learning	*Flipped Classroom*	*Gamification*	*Internship, Co-op, Site Visits*	*Service Learning*	*Laboratory*	*Multidisciplinary Collaboration*	*PBL, PjBL, CBL*	*Project Teams*	*Self-Directed Learning*	*Study Abroad*	*Summer Program*	*Virtual/Augmented Reality*
Collaborative Learning		1	1	2	2	**3**	1	**4**	1	2	1	2	2
Flipped Classroom			1	1	1	2	1	2	1	1	1	1	1
Gamification				1	1	1	1	1	1	1	1	1	2
Internship, Co-op, Site Visits					2	2	1	1	1	1	1	2	1
Service Learning						2	1	2	2	1	**3**	2	1
Laboratory							1	**11**	**6**	2	1	2	2
Multidisciplinary Collaboration								1	**3**	1	1	1	1
PBL, PjBL, CBL									**16**	**4**	1	1	2
Project Teams										2	2	1	1
Self-Directed Learning											1	1	1
Study Abroad												1	1
Summer Program													1
Virtual/Augmented Reality													

Discussion

This review of EL opportunities implemented in engineering education has identified patterns in how EL is implemented and assessed. Overall, the majority of articles looked at classroom experiences within the context of one discipline or without making disciplinary distinctions for comparison. Experiential learning settings frequently incorporated features of *problem (PBL), project (PjBL), or challenge-based (CBL) learning*, *laboratory* settings, and work in *project teams*. Articles also frequently used a course or program evaluation approach to assess impacts on students based on grade changes or course surveys that asked about student satisfaction with the course. Based on those findings, this review discusses how current assessment and evaluation strategies for EL opportunities impose limitations on broad conclusions that can be drawn about the impact of EL. Recommendations for future research to push the field towards a broader understanding of EL in engineering are also discussed.

Study Population and Context. Two key gaps in the literature emerged when examining the study population and study context codes assigned to articles in this review. Both gaps relate to limitations of the research performed on EL. First, research using EL models to develop or assess co-curricular/extra-curricular learning contexts was lacking. Very few articles (n = 21) (Ayob et al., 2011, 2012; Basu et al., 2017; Callewaert, 2019; Chan, 2012b; Dominguez-Ramos et al., 2019; Gadhamshetty et al., 2016; Henry et al., 2016; Laguador & Chavez, 2020; W. Lee & Conklin, 2016; Li et al., 2015; Litchfield et al., 2016; Litton et al., 2018; Noguez & Neri, 2019; Ortegon, 2016; Panzardi et al., 2015; Simpson et al., 2012; Siniawski et al., 2015; Wilkerson et al., 2017; Wittig, 2013; Zhu et al., 2019) in this review examined a co-curricular/extra-curricular learning context. With a wide range of co-curricular/extra-curricular opportunities (e.g., service learning, co-op or internship experience, project teams, etc.) represented in these studies, it was difficult to identify patterns that could indicate promising assessment strategies or common outcomes across the experiences since studies assessed a range of technical, professional, and personal outcomes (see Figure 4 for distribution of assessment topics). Studies in this review focused on co-curricular/extra-curricular opportunities also commonly looked at multiple disciplines and with fairly small sample sizes. Only a few studies examined data from more than 100 students with quantitative assessment methods (Laguador & Chavez, 2020; Li et al., 2015; Litchfield et al., 2016; Zhu et al., 2019). Given that co-curriculars/extra-curricular opportunities have been consistently identified as impactful experiences in engineering education (Fisher et al., 2017), understanding the role of EL models in developing opportunities and assessing learning these contexts is similarly important.

Second, many of the articles in this review described classroom studies. A majority of the articles took place in the context of *one discipline* or *one course without major distinctions*. Numerous disciplines were represented in the studies, ranging from more common majors like electrical and mechanical engineering to less common majors like telecommunication and textile engineering (see Supplement 1 – available upon request). Frequently, articles that describe a study situated within one course aligned with Scholarship of Teaching and Learning (SoTL) research practices in engineering education where the studies ask questions specific to an instructor's classroom (Streveler et al., 2007). While SoTL studies can be rigorously performed and are usually more accessible to educators who have just begun education research, studies like these are typically less generalizable and have a lower potential for broad impacts to engineering education research than studies that align with research at Level 4 (Rigorous Research in Engineering Education) as described by Borrego and colleagues in their interpretation of research in engineering education (Borrego et al., 2008; Streveler et al., 2007). The four levels of research in their description are excellent teaching (level 1), scholarly teaching (level 2), SoTL (level 3), and rigorous research in engineering education. Levels 3 and 4 of inquiry are similar in that they are

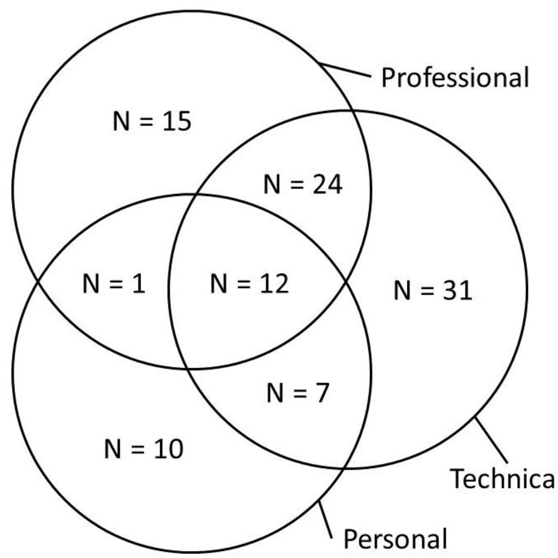

Figure 4. Assessment Topic coverage by paper.

public and open to critique allowing for other scholars to build on the work performed; however, inquiry at level 4 incorporates research questions, educational (learning, pedagogical, or social) theory, and established educational research methods that create a potential for broader impacts of the study's results.

A limited number of articles described research methods that move the evaluation of their EL opportunity toward Level 4 on the spectrum of engineering education research inquiry. One example includes a study of the impact of problem-based learning (PBL) pedagogy on teaching the critical path method in a civil engineering course (Forcael et al., 2015). The authors posed a set of questions they sought to address through the work, used PBL literature to inform the design of the intervention, and used what they described as a sequential mixed method approach to data analysis. However, in line with findings by Borrego and colleagues, the relatively few articles attempting research that approaches 'Rigorous Research in Engineering Education' indicated that faculty may need help performing research on EL opportunities that moves beyond SoTL inquiries (Borrego et al., 2008). As such, it may be necessary for institutions to provide resources (i.e., training, funding, facilitation of research collaborations) to perform that work. One example of an existing resource at many research institutions that may be leveraged to perform research that moves beyond SoTL could include centers for research on learning and teaching (CRLTs). Typically, these centers focus on the improvement of teaching by increasing the implementation of evidence-based teaching practices, however, they may also provide workshops focused on education research and evaluation best practices, as well as internal funding that could support monetary needs associated with research studies that have broader impacts.

One article in this review described the efforts of a college of engineering to understand the impact of EL opportunities in their college (Callewaert, 2019). The article examined EL opportunities in curricular and co-curricular/extra-curricular study contexts. Looking at self-reported technical and professional outcomes from a college-wide survey, the article used Likert-like, self-report questions to examine the impact of EL initiatives like study abroad, honors programs, teaching assistantships, design and creative projects, team competitions, and research projects on their campus (Callewaert, 2019). They found differences between students self-reported gains in outcomes like conducting research, leadership, comprehending academic material, understanding their field of study, teamwork, writing, critical thinking, and communication when comparing students who did participate in EL opportunities to those who did not. This article demonstrates one assessment strategy that has the potential to examine the impact of EL across contexts. Though the conclusions about development are limited because the learning outcome measures used were not direct measures, it gives some alternative insights into how engineering colleges can begin to scale EL assessment efforts across curricular and co-curricular contexts that is not dependent on faculty training or synthesis across study contexts.

Assessment Method. Insights on future research directions that could improve a broader understanding of the impact of EL in engineering education could also be drawn by looking at patterns in the assessment method codes. Many of the articles used assessment strategies that employed SoTL approaches to understanding learning outcomes in their context, and very few articles took advantage of insights that could be gained by employing qualitative or mixed methods approaches to inquiry. Findings in this coding category further support the idea that a broad understanding of the impact of EL in engineering education may benefit from the use of previously established engineering education research methods and measures.

Much of the assessment performed aligned with the *program/course evaluation* code. This code was meant to represent assessment efforts that a) developed their own assessment or evaluation tools for the particular learning setting, without drawing questions from education literature or b) did not describe the methods used to set up the study. Many articles coded as *program/course evaluation* were articles describing an instructor's experience trying a new EL initiative and either gaining students' perspectives on the value of the experience or measuring their success based on grades. For example, Hassan and colleagues looked at the learning gains of third-year automation and electronic engineering students in a project-based versus a traditional learning method industrial informatics course finding that students in the project-based version performed better on exams and had generally positive views of the project-based pedagogy (Hassan et al., 2015). While *program/course evaluation* studies are valuable for identifying successful implementations of EL opportunities, the context specificity of these studies often limits the transferable knowledge that can be gained.

Additionally, very few articles in this review employed qualitative research methods (n = 9 qualitative and n = 7 mixed methods). Multiple engineering education researchers have emphasized the importance of a balance of methodologies when studying phenomena in education research citing that quantitative and qualitative studies frequently seek to answer different questions (Borrego et al., 2009). In particular, qualitative and mixed methods studies may benefit knowledge in this field by improving researchers' understanding of how or why EL opportunities impact student outcomes in engineering education. By focusing on measuring the outcomes of the opportunity, important information about the structures and features of the experience that support the learning are missed. The questions asked (typically 'how' and 'why' questions) and the data collected (typically through interviews, open-ended questions, or observations) in qualitative studies are well suited for exploring the nuances in student experiences as well as features of EL settings that are beneficial for student development which are currently understudied in EL literature. Other reviews of EL in engineering education have highlighted the potential value of future qualitative research methods in their discussion sections (B. Johnson & Main, 2020). Similarly, studies using a combination of quantitative and qualitative approaches (mixed methods) to assess experiential education could prove beneficial to the overall understanding of the impact of EL in engineering education. Robust mixed methods studies frequently require larger resources to conduct (e.g., time, money, etc.) and as such may also benefit from improved access to resources for instructors and researchers wishing to perform this work. High numbers of *program/course evaluation* articles and low use of *qualitative, quantitative, or mixed methods* approaches indicates that many articles in this review did not employ robust (level 4) methods for examining the impact of the EL strategy employed.

Experiential Learning Setting. Finally, much can be learned by examining patterns in the co-occurrence of EL setting codes (see Table 6). Co-occurrence patterns in these codes provide insights into complementary settings and pedagogies that may facilitate EL that administrators and educators could use to develop EL opportunities. Further, multiple patterns of co-occurrence were found in the codes assigned that may be worth exploring in future research.

One major pattern of co-occurrence observed was the high frequency of articles assigned a *problem (PBL), project (PjBL), or challenge-based (CBL) learning* code. Half of the articles analyzed incorporated some aspect of *problem (PBL), project (PjBL), or challenge-based (CBL) learning* (n = 50) in the EL setting category. Two key takeaways resulted from this observation: 1) PBL, PjBL, and CBL pedagogies are increasingly common pedagogical strategy in EEE efforts and 2) co-occurrences of the PBL, PjBL, and CBL code with codes like *project teams* or *laboratory* indicate opportunities for educators to incorporate PBL, PjBL, and CBL in those settings.

A majority of articles coded as *problem (PBL), project (PjBL), or challenge-based (CBL) learning* were also coded as *program/course evaluation* (n = 32 of 50) in the assessment methods category, which indicates that while pedagogical approaches used to implement *problem (PBL), project (PjBL), or challenge-based (CBL) learning* are common in studies related to EL opportunities, the assessment and evaluation efforts could be improved to be more transferrable or generalizable. A few of the articles in this review implemented strategies to improve the transferability or generalizability of their findings to varying degrees. They are cited here as a reference for instructors interested in increasing the potential impact of their classroom research (Dolan et al., 2011; Fini & Mellat-Parast, 2012; Schilling & Klamma, 2010; Torres et al., 2016; J. Turns et al., 2010). For example, articles in this review that studied *problem (PBL), project (PjBL), or challenge-based (CBL) learning* settings in a more transferrable way used educational learning theories to develop learning opportunities, assessment resources like pre-established quantitative scales (e.g., Rucker's continuum of values in (Dolan et al., 2011)), and established engineering education research methods like qualitative follow-up interviews to increase the broader impacts of the work. These articles demonstrate the value that using prior work in engineering education research can bring to faculty's assessment efforts, even in a classroom setting.

Many of the articles coded *problem (PBL), project (PjBL), or challenge-based (CBL) learning* were also assigned *project teams* and/or *laboratory* codes. The co-occurrence may be due to the alignment of a *problem (PBL), project (PjBL), or challenge-based (CBL) learning* pedagogical approach that aligns with learning that occurs in *project teams* or *laboratory* settings. The observed co-occurrence may also relate to a relatively recent emphasis on design education in engineering curriculum. Aspects of design education would be captured in the *problem (PBL), project (PjBL), or challenge-based (CBL) learning* code as well as the *project teams* and *laboratory* codes based on the way they were defined in the open-coding process. Design in engineering education has been cited as an opportunity for students to gain hands-on, real-world experience which aligns well with the EL process (Conger et al., 2010; Harrisberger, 1976). An alignment of EL processes with existing design education in engineering indicates an opportunity for educators to improve already existing curriculum. Informing assessment and evaluation efforts in these spaces using previous findings and methods in engineering education would further benefit the overall understanding of the impact of EL in engineering design education.

Another interesting pattern of co-occurrence in an examination of EL setting codes was of *study abroad* and *service learning*. Each code occurred four (4) and thirteen (13) times respectively, co-occurring together three (3) times. Overall, the majority of the articles assigned *study abroad* were also assigned *service learning* (Callewaert, 2019; Dinehart & Gross, 2010; Panzardi et al., 2015), which indicates a potential pattern in the way that engineering students experience study abroad. The literature on study abroad for engineering students has previously discussed numerous barriers to engineering students choice to participate in study abroad, one of which is incorporating a study abroad experience for engineers wishing to graduate in four years (Klahr & Ratti, 2000; Warnick et al., 2018). At the same time, service learning literature in engineering often describes service abroad design experiences for engineering students. These patterns may indicate that engineering students who wish to have a study abroad experience without adding time to their degree may opt for a shorter study abroad design experience. While these experiences have demonstrated value for students in achieving professional and engineering outcomes, they have also been critiqued for their sometimes limited consideration of the impact on the stakeholders of partner communities (Schneider et al., 2009; Smith et al., 2020). As educators and administrators develop study abroad experiences for engineering students, they should take into consideration student concerns about barriers to participation as well as work to create a design abroad experience for engineering students with equal importance placed on student outcomes and community impacts.

Limitations. Systematic literature searches "seek to draw together all known knowledge on a topic [20, p. 102]" using transparent search and appraisal methods so others can critically examine or replicate the work. Because engineering education research is an interdisciplinary field that draws upon multiple other scholarly disciplines to inform their theories and methods, identifying search and appraisal criteria to capture all relevant knowledge on a topic can be challenging. Further, multiple interpretations of what EL is made scoping a review on the assessment and evaluation of EL in engineering undergraduate contexts difficult. While developing search terms for this study, the authors intentionally used the search terms "higher education" and "HEI" to narrow the literature search to engineering education contexts that did not include pre-college engineering education, a growing area of research in the field. In doing so, articles that did not use the term higher education, but were nonetheless in engineering higher education contexts may have been missed. This highlights an important area for future work aiming to understand the implementation and assessment practices used to research EL in engineering education. While this study is a substantial first step towards a broader understanding of how and where EL is currently evaluated in undergraduate engineering, more work is necessary as the field evolves. Researchers looking to extend or validate the work presented here could employ different search term combinations (e.g., "engineering education" AND NOT ("K12" OR "pre-college" OR "graduate")) to identify other articles relevant to the research questions posed. Other future work may instead focus on graduate or pre-college EL contexts to see if similar assessment and implementation patterns emerge. Additional work could also explore different aspects of assessment (e.g., specifics of the student outcomes measured, types of assessment resources used, etc.) that were not explored in depth by this study.

Additionally, this review followed systematic search strategies that aimed to incorporate articles on both curricular and co-curricular/extra-curricular EL opportunities. However, upon completing the review, the authors recognized that the search terms used to identify articles in the first search stage (see Figure 1) of this review did not capture some co-curricular/extra-curricular articles that were expected based on their understanding of the co-curricular/extra-curricular literature. One potential explanation for this limitation is that the search terms did not explicitly include terms related to the setting of the EL opportunity. Studies that the research team would have included based on their screening criteria but were not captured in the search phase of the review include (Benson et al., 2016; Burt et al., 2011; Carter et al., 2016; Dukart, 2017; Kneale et al., 2016; Denise Rutledge Simmons & Groen, 2018). In line with discussions from other scholars examining EL through literature reviews, this limitation highlights the complex application of EL across engineering education research (Morris, 2019). Further, the limited number of co-curricular/extra-curricular articles identified in this review created a limitation on the extent to which patterns could be examined across EL studies in the co-curricular/extra-curricular setting. Future EL reviews may wish to examine in class (*course/program)* and out-of-class (*co-curricular/extra-curricular*) settings separately for a more detailed understanding of how research is performed in each context, ensuring that studies in each context are adequately captured in the search phase of the literature review. Despite the limitations addressed above, this review is a key first step towards understanding how EL has been implemented and evaluated in engineering education and provides areas for future exploration of the topic.

Conclusions. This literature review explored the current trends in how engineering education research has implemented and assessed the impact of EL in engineering education. Results from this study indicate common assessment and implementation strategies that show promise for future efforts to incorporate EL in engineering education. Findings also indicate areas that could benefit from more research. Suggestions for future work to inform implementation and assessment of EEE are provided below:

- More research is needed to understand how EL models can be used to create EL opportunities and measure the outcomes within co-curricular/extra-curricular learning contexts.
- Classroom studies should consider the benefits of incorporating assessment that applies robust engineering education research methods or measures to improve the understanding of the impact of experiential education efforts across classroom contexts.
- Researchers should consider the benefits of qualitative and mixed methods approaches when designing studies that examine outcomes of experiential education.
- Improving access to resources for faculty wishing to perform robust education research may be necessary. Previously proposed ideas for increasing the application of engineering education findings in classrooms include: access to education research workshops, facilitating partnerships with education researchers, and funding or reward structures to support education research endeavors (Streveler et al., 2007).
- Future research may wish to explore how study abroad faculty and administrators consider the impact of study abroad, service learning opportunities for engineering students on the stakeholders in partner communities (Schneider et al., 2009).

Overall, this literature review indicates a vast existing body of research on learning opportunities that incorporate EL into engineering education. This review aimed to expand work exploring EL in engineering by examining ways researchers might improve the extant knowledge of the impact of EL in future work. This work further contributes to field by proposing suggestions for how future work can improve evaluation efforts on EEE.

CHAPTER III

BME Students' Perspectives on the Value of Co-Curricular Experiences

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Abstract. *Many studies have examined student engagement in university settings as a predictor for learning and development, finding that generally, higher engagement is linked to gains in professional outcomes and persistence. Engineering student engagement research has been performed on co-curricular experiences and has led to an increased emphasis from institutions on students' participation in those experiences. Similarly, BME students regularly engage in co-curriculars to supplement their experience in the formal curriculum because of concerns about their professional marketability when they graduate. To help students make an informed co-curricular engagement choice, it is important to understand not only what professional outcomes students gain from their co-curriculars as has been previously studied, but also what about the co-curricular is valuable to their initial engagement and continued participation. This study employs a qualitative study design and the four dimensions of subjective task value described in Eccles' expectancy value theory of motivation to explore BME students' engagement in co-curricular experiences. The goal of the study was to better understand why students participate in co-curricular experiences beyond the findings of previous studies which focus on the technical and professional outcomes of participation as well as more deeply explore the way students relate their participation to their preparation for future careers.*

The results of the study indicated that BME students are largely motivated to participate in co-curricular experiences for their utility value in leading to a career in

BME, which is consistent with outcomes-focused prior studies. Beyond that, students discussed the ability to connect how they see themselves as a biomedical engineer and a general interest in the work and non-career related opportunities available to them through their co-curriculars. While the discussion of cost was minimal in our study, time was also a factor for students' decision to participate in co-curriculars. These additional findings indicate that students can also be motivated to participate in co-curriculars through other means than just the outcomes studied in prior co-curricular literature.

Introduction

Student engagement in higher education settings has long been studied as a predictor for college student learning and development (Mayhew et al., 2016). Broadly, studies of student engagement have often examined relationships between a student's educational experiences and the outcomes of interest, finding that, in general, higher engagement was linked to gains in outcomes such as learning and persistence (Kuh, 2001, 2009). In particular, engagement in co-curricular settings, or experiences outside the classroom, has been linked to the development of several technical and professional outcomes for engineering students such as leadership, ethical decision making, teamwork, and communication (Burt et al., 2011; Busby, 2015; Fiorini et al., 2014; Fisher et al., 2017; Litchfield et al., 2016; Young et al., 2015). Beyond those outcomes, co-curricular engagement has also been linked to outcomes such as self-efficacy and a sense of belonging, which can improve retention and persistence in engineering students (Burt et al., 2011; Fiorini et al., 2014; Fisher et al., 2017). Research on co-curricular experiences has led to an increased emphasis from higher education institutions on students' participation in co-curricular experiences (Busby, 2015; Conger et al., 2010). BME undergraduate students have explicitly implicated co-curriculars as a key part of preparing them for professional careers in their undergraduate experience (Berglund, 2015b). BME students often choose to engage in one or more co-curricular experiences to supplement their professional development through the formal curriculum because of concerns about their professional marketability upon graduation (Berglund, 2015b; Nocera et al., 2018).

Because a student's decision to engage in a co-curricular experience is largely non-compulsory, understanding what informs students' choices to engage is an emerging area of research for engineering education (Aileen Huang-Saad & Celis, 2017; Shekhar et al., 2018). Findings from such research can help educators support the development of effective co-curricular programming and advise students in paths to participation. Fisher et al. (Fisher et al., 2017) explored engineering students' selection processes through a synthesis of previous findings on co-curricular engagement; their framework details "types" of co-curriculars and the outcomes linked to them. In order to help students make an informed engagement choice as well as inform "what types" of co-curriculars are available to students, it is important to understand not only what professional outcomes students gain from their co-curricular experiences, but also what else about the co-curricular is valuable to their initial engagement and continued participation.

This study focused on BME students' engagement in co-curricular experiences to better understand why they participate in co-curricular experiences and how they view their participation in relation to their preparation for their future careers. Qualitative data was collected from semi-structured interviews to examine two types of co-curricular experiences in which BME students frequently engage at one Midwestern university.

Background

The study of student engagement in higher education has roots in Astin's (1984) concept of involvement and Pace's (1998) research on a related concept he called quality of effort. Both scholars postulated that the more time and energy a student devotes to the academic experience, the more that student will learn. Astin argued that involvement, or the investment of physical and psychological energy towards an experience, occurs on a continuum and has both quantitative (e.g. time on task) and qualitative (e.g. useful study strategies) features (Astin, 1984). Astin and Pace's work is the basis for the National Survey of Student Engagement (NSSE) which collects five categories of information about students: participation in educationally purposeful activities (e.g. interacting with faculty or peers), what institutions require of them (e.g. amount of reading or writing), perceptions of features of the environment related to academic success, demographic information (e.g. gender, race, socioeconomic status, major, etc.), and estimated growth in various outcomes since college (Kuh, 2001, 2009). While there is some debate on the predictive power of NSSE, studies using NSSE have linked student engagement in co-curricular experiences to student learning outcomes, increased retention, and four year graduation (Busby, 2015; Fiorini et al., 2014).

Beyond NSSE, many other studies have linked student outcomes to co-curricular experiences. These studies often focus on collecting data on “who” they are studying by identifying the characteristics of the student population, “what types” of co-curriculars support students’ learning by selecting one or more co-curricular experiences, and “what outcomes” are achieved by assessing specific student outcomes (Carter et al., 2016; Finelli et al., 2012; Lattuca et al., 2017; Litchfield et al., 2016; Young et al., 2015). For instance, a study by Young and colleagues (Young et al., 2015) collected data on African American engineering students in a variety of co-curricular activities that the researchers classified into three categories (engineering clubs, underrepresented minority (URM) clubs, and other clubs). The study analyzed the perceived development of communication, professionalism, lifelong learning, teamwork, and reflective behavior skills related to co-curricular participation. Some findings from the study include higher reported teamwork and reflective behavior related to participation in any of the three categories of co-curriculars, lower reported communication skills for students participating in URM clubs when compared to peers who did not, and higher reported teamwork skills with increased involvement in engineering and other clubs. Using a similar approach, a study by Litchfield et al. (Litchfield et al., 2016) assessed the differences between engineering students and practicing engineers who were involved and not involved in engineering service experiences. The study found that both populations perceived similar levels of technical skills, but that participants with engineering service experience reported significantly higher professional skills, statistically controlling for potential relationships between skills and age, gender, and grade point average. A study by Carter et al. (Carter et al., 2016) also sought to study engineering students in a specific co-curricular environment, undergraduate research, to determine effects on student outcomes like communication, teamwork, and leadership skills. An important finding of this study was the effect self-selection into co-curriculars like undergraduate research can have on studies using self-report measures of student outcomes as a comparison tool. The study found that students who engaged in undergraduate research tended to report higher skills, but when accounting for both curricular and classroom experiences, few differences were seen between students who did or did not participate. This and similar work have contributed to knowledge about "what types" of engagement in co-curricular experiences are most significant for engineering students. Until Fisher et al.'s recent work, however, a thorough review of the potential relationships between specific co-curricular opportunities and potential engineering student outcomes had not been performed (Fisher et al., 2017).

Using their review to develop a framework, Fisher and colleagues (Fisher et al., 2017) categorized the various types of co-curricular experiences and documented what outcomes could be linked to the co-curricular types. The extensive set of outcomes identified include: Civic Responsibility, Creativity, Critical Thinking, Cross-Cultural Skills, Disciplinary Knowledge, Ethics, Global Awareness, Humanitarianism, Interpersonal Communication, Memory, Networking, Organizational Management, Problem Solving, Public Speaking, Self-Confidence, Self-Direction, Strategy, Teamwork, Time Management, and Written Communication, which they link to 22 types of co-curricular experiences. They suggest that this work could be used to help advise engineering students in identifying and selecting co-curricular experiences with which to engage. While these findings may inform students' decision making processes based on desired outcomes, it does not account for other student motivations for participating in these optional educational experiences. In fact, few studies (Dalrymple & Evangelou, 2006; Mulrooney, 2017) exist that examine if the outcomes in the literature align with what motivates students to engage in co-curricular experiences. If researchers and practitioners desire to encourage student participation in co-curricular experiences, we must also understand why they choose to engage.

Further, studies have not focused on the field of BME, where co-curriculars play a very important role in the undergraduate experience. Berglund quoted BME baccalaureate graduates' views of the importance of co-curricular involvement in their experience; students said things like: “You really had to go beyond the classroom to learn about other opportunities… (p. 47)” and “If the goal is for students to land jobs right out of college… BME programs should strongly encourage students to participate in research… (p. 49)” (Berglund, 2015b). BME students often share the concern that they will be ‘jacks of all trades, and masters of none’, with limited marketability to industry (Nocera et al., 2018). In an effort to address these concerns, BME students often look to co-curricular experiences to round out their undergraduate experience. Because BME students are emphasizing the need to incorporate co-curriculars into their undergraduate experience (Berglund, 2015b; Nocera et al., 2018), BME educators need to help guide students in selecting co-curriculars that align with their wants and needs.

Study Design

This study was guided by the following research question:

Why do BME students participate in one or more common co-curricular experiences?

Data to inform this question were collected as part of a larger longitudinal, qualitative study of BME students’ experiences in two co-curricular experiences. Qualitative research primarily seeks to understand the lived experience of participants asking questions about how people interpret their experiences or what meaning they attribute to their experience (Merriam, 2009b). This paper used an interpretive, conventional content analysis approach to establish findings (Hesse-Biber & Leavy, 2017; Hsieh & Shannon, 2005). In performing the content analysis, it was found that the data could be connected back to theory, which is described in the results and discussion.

Study Site & Co-Curricular Experiences. This study was conducted with students in the BME department at a large, research intensive, public university in the Midwest United States. Students enroll in one of three concentrations within the undergraduate major: bioelectrical, biochemical, and biomechanical. In addition to coursework, students in the BME department often participate in one or more co-curricular experiences before graduation, but co-curricular participation is not required as part of the curriculum. Common experiences include the two studied (Multidisciplinary Design Experience, or MDE, and Undergraduate Research) along with other professional and departmental societies and internship opportunities. The multidisciplinary design experience and undergraduate research experiences were selected for this study because 1) a high percentage of students in the department participate in one or both experiences 2) they exemplify two different "types" of co-curricular experience based on Fisher's categorization (Fisher et al., 2017) 3) similar experiences have been frequently studied in engineering education and 4) students typically engage with the MDE and research experiences for an extended time allowing for longitudinal data collection which is part of the larger study design. These criteria allowed for selection of co-curriculars where study participants could be recruited, compare and contrast the experiences, as well as utilize previous work to inform the questions and analyses of this study.

Multidisciplinary Design Experience (MDE). The MDE student group focuses on addressing healthcare problems by fostering interdisciplinary work in global health and applying design and entrepreneurship strategies. While approximately half of the 300 student members are BME majors, many other majors participate in MDE (e.g., electrical engineering, mechanical engineering, materials science, computer science, public health, business, etc.). Students can participate in the organization in multiple ways: as a design incubator participant, on a design team, on a travel team, or as a board member.

Undergraduate Research Experience. Undergraduate research provides students with an opportunity to get exposure to research. It is commonly recommended that undergraduate students gain research experience at the university where the study took place, though what kind of research is not specified. There are several mechanisms for students to become involved in research, through independent study credit, for hourly pay, or volunteering. It is not uncommon for research experience to vary dramatically between labs, with regards to the tasks performed by undergraduate researchers or the level of input taken in project decisions.

Participants. Using purposive and snowball sampling (Saldana & Omasta, 2018), 14 students entering their third year, who were also planning on engaging in at least one of the two co-curriculars studied (MDE and undergraduate research) over the

1.5 years study period, were invited to participate. Fourteen participants is within the range of a typical sample size in a qualitative study (Saldaña & Omasta, 2018) (p. 179); qualitative research studies rarely seek to generalize results but rather ask questions that allow for an in-depth understanding of a specific environment (Hesse-Biber & Leavy, 2017; Merriam, 2009b). Participants varied by self-reported gender, race/ethnicity, pursued concentration, level of engagement with the co-curricular as categorized by the first author, and career aspirations (see Table 7 and Table 8 for details).

Table 7. Participant demographic data (n = 14).

Gender	Female (11)	Male (3)	
Race/Ethnicity	Asian (6)	Hispanic/Latinx (2)	White/Caucasian (6)
Co-Curricular	MDE (9)	Research (11)	Both (6)
Concentration[1]	Biochemical (6)	Biomechanical (6)	Undecided (2)
Career Aspirations[2]	Short Term • Gap Year (2) • SUGS[3] (7) • Doctoral (3) • Industry (2)	Long Term • Doctoral (2) • Industry (12)	

Table 8. Participant co-curricular level of engagement at time of data collection.

	MDE Participants (9)			**Undergraduate Research Participants (11)**		
Level of Engagement	High (7)	Middle (0)	Low (2)	High (4)	Middle (6)	Low (1)

Data Collection. Before data collection began, this study was determined to be exempt from IRB regulation. Semi-structured interviews lasting 45 minutes to 90 minutes were conducted to explore student perspectives regarding the goals of the co-curricular, reasons for joining, their experiences, and how they would describe the co-curricular to a friend. In-depth interviews, like the ones conducted in this study, allow for the interviewer to ask follow-up questions that encourage participants to provide answers that move beyond simple responses and into more complex thought processes. Questions were developed by the research team, piloted, and adjusted to facilitate better discussion with participants and improve the researchers' understanding of meaningful experiences students had through their participation. A second set of

[2] Concentration and Career Aspirations data was compiled using questions in the second interview of the full study.
[3] SUGS is the Sequential Graduate Undergraduate Study program offering a one year Master's degree after completion of the Bachelor's degree at our institution.
(#) Indicates the number of participants in that category.

interviews at the end of the semester was performed as part of the larger study and some data from those interviews has been included in this paper where indicated. All interviews were completed in Fall 2019 and transcribed verbatim for analysis. The first author performed all interviews and employed memoing strategies to further inform and adjust interview questions as needed to explore the research question (Hesse-Biber & Leavy, 2017).

Data Analysis. An interpretive qualitative approach aligned with conventional content analysis was used to explore and understand the attributes of a co-curricular experience that students found meaningful (Hesse-Biber & Leavy, 2017; Hsieh & Shannon, 2005). Students are identified in the analysis using the pseudonyms they chose. Coding in qualitative research is a process of assigning a word or short phrase to summarize or capture salient attributes of a portion of qualitative data (Saldana, 2016a) which, in the case of this study, was transcribed interviews. The analysis process started with descriptive coding of the transcripts to identify areas of the interview related to the research question. Then, categorical codes were developed to identify common categories of discussion throughout the interviews. Categorical codes were then grouped by the co-curricular discussed and analyzed to capture meaning within the groups. The steps taken in the analysis process align with rigorous qualitative data analysis recommendations (Auerbach & Silverstein, 2003).

By organizing categorical codes into groups, it was found that participants' discussions of their experiences could be interpreted using subjective task value (STV) as defined in Eccles' expectancy value model. Subjective task value is a central construct of Eccles' expectancy-value theory of achievement motivation (EVT) (Eccles, 2005). EVT seeks to explain how individuals choose behaviors based on their outcome expectations and the value they place on that outcome (Wigfield & Eccles, 2000). Subjective task value can be broken into four dimensions:

1. Attainment Value: A task has attainment value if it provides a way to confirm or support an aspect of how one sees one's self.
2. Interest Value: A task has interest value if an individual enjoys or expects to enjoy doing the task.
3. Utility Value: A task has utility value if it benefits future plans.

4. Cost Value: A task can also have perceived cost(s) associated with performing the task.

While EVT is more commonly used to predict a subject's behavior, for this paper, the STV construct of EVT was used to assess students' perceived value of co-curricular participation. This approach is similar to that used by May in a study of engineering students' experiences with service learning (May, 2017). May assessed the value of a service learning program by examining student perceptions of eight values categories previously developed by the researcher (i.e., intrinsic, altruistic, impact, attainment, career, cost, camaraderie, community values). Using this method, May found that career value was a prominent theme across student respondents and made suggestions for improving the program.

Instead of asking students to respond to pre-determined STV categories, interview responses were categorized into codes and mapped to the four STV dimensions (attainment, interest, utility, cost). The results of this study compare and contrast what value students place on their participation in two different co-curricular experiences as well examine common values across experiences.

Results

For both co-curricular experiences, MDE and undergraduate research, resultant codes could be categorized as one of the four subjective task values of attainment, interest, utility, or cost (see Table 9 and Table 11 for examples). Some codes were consistently identified for both MDE and research (i.e., having a community, learning course and engineering concepts through application, and it takes a lot of time). The least frequent value discussed was perceived cost. Students participating in the different co-curriculars tended to differ in their discussion of attainment and interest values. MDE participants tended to articulate more attainment value, while research participants more often described interest values. Expressions of utility value were most numerous for both groups. When discussing the codes that were categorized as utility values, participants often related them to their utility for preparing them to enter an engineering professional setting or develop relevant professional skills outside of the classroom. Within these discussions, evidence was found of students' perceived difficulty with getting a job with only a BME bachelor's degree, which was interpreted as a strong motivator for BME students to engage in co-curriculars and improve their career outlooks.

Multidisciplinary Design Experience. The nine MDE participants described 11 different subjective task values (see Table 9). Most of the values were associated with utility and directly aligned with developing the competencies necessary to work in industry: communicating in a professional setting, being an organization and/or team leader, working in a team, designing in a BME context, or networking with industry and stakeholders. While there were only two codes for attainment value, both were shared by the majority of the participants. Eight participants discussed the value of having a community and seven mentioned a desire to help others through their work. Only one interest value was identified in our study: travelling somewhere new. Very few participants discussed potential costs of engaging in the MDE; the only code associated with perceived cost was the amount of time required to engage fully. Despite that acknowledgement, participants described the time investment as worth it. Exemplar quotes are provided in Table 10.

Table 9. MDE inductive coding descriptions.

SVT Dimension	Codes	Participants describe…
Attainment Value	*Having a Community*	having people they can count on, finding their "group", or gaining a community.
Attainment Value	*Helping Others Through My Work*	the ability to help, influence, positively impact others through their work.
Cost Value	*It Takes a Lot of Time*	the time it takes to engage in the co-curricular as substantial and potentially conflicting with other priorities.
Interest Value	*Travelling Somewhere New*	the ability to travel both domestically and abroad.
Utility Value	*Exploring Industry Careers*	the ability to gain new insights on what BME professional settings (e.g., industry, graduate school, medicine) are like.
Utility Value	*Communicating in a Professional Setting*	the ability to get exposure to or develop skills in various forms of professional communication (e.g., written, presented, in meetings).
Utility Value	*Being an Organizational and/or Team Leader*	the ability to get exposure to leadership positions or develop leadership skills.
Utility Value	*Working in a Team*	the ability to work with a team for an extended time.
Utility Value	*Designing in a BME Context*	the ability to gain design exposure in a context that they enjoy (BME problems).
Utility Value	*Networking with Industry and Stakeholders*	the ability to engage with and learn about a wide variety of industries and stakeholders.
Utility Value	*Learning Course and Engineering Concepts through Application*	the ability to learn by doing or the desire to improve classroom learning by applying knowledge in context.

Table 10. MDE subjective task value, corresponding codes, and representative quotes.

<table>
<tr>
<td>Attainment Value:

Having a Community

"MDE is a place really will help foster growth in whatever direction you want to take it, whether it's growing a sense of community and having a family or a team that you can count on…" - AJ

Helping Others Through My Work

"I decided to join MDE because I am interested in global health. I think that I would love to see a world where you live or how much money you have doesn't dictate what your quality of healthcare is. I wanted to be in an organization that was working toward addressing those disparities." - Ernest</td>
<td>Interest Value:

Travelling Somewhere New

"It's given me the opportunity to travel within the United States because that was part of the SOUND trip. There's obviously more opportunities to travel I think with the SPA trip, and then just individual design team trips as well." - Detroit</td>
<td>Cost:

It Takes a Lot of Time

"I think classes are always a priority for me. I know I can maybe take a step back. I actually recently had a conversation with a friend about potentially still trying hard in my classes, but maybe trying to spend a little bit less time actually studying outside of class so that I do have time to commit to my co-curriculars where I really am learning a lot more than I sometimes am in the class, which is really hard for me to say and probably even going to be harder for me to do." – Ernest</td>
</tr>
<tr>
<td colspan="3">Utility Value:

Communicating in a Professional Setting

"Like, yes, MDE is very interdisciplinary... I'm hoping that's how project teams in the future will be like in the workplace where you'll be working with a bunch of people from different areas. And… as a biomedical engineer, as someone who has been a part of MDE, you could be the one to connect the nurse to the electrical engineer and be able to understand what they're both saying." - AJ

Being an Organizational and/or Team Leader

"I think also leadership, there are a lot of leadership opportunities if you are committed and if you're willing to devote your time and energy." - Al

Working in a Team

"I wanted to get the experience of working on a team and really bonding with that team on a single project over the course of several years and not in sort of a competition style where you build the robot..." - Ernest

Designing in a BME Context

"I think that MDE has shown me what engineering design really is, and what kind of a process it can be." - Timmy

Networking with Industry and Stakeholders

"We are sponsored by several medical device companies, so we host different information sessions, networking events. And that way, there are opportunities for professional development. And project teams, I think they work with mentors from medical device companies, so they have connections, that way. And the travel teams, we definitely learn a lot from different organizations and from the people in the community." - Student M

Learning Course and Engineering Concepts through Application

"Yeah, I was interested in learning about materials because I was interested in the material background, but I ended up getting put on a different (sub)team. I learned a lot about circuit design and circuit testing, which is helping in some of my classes right now." - Detroit

Exploring Industry Careers

"I think that, so far, if I was not involved in MDE, and I was only taking my BME classes and even just only involved in research outside of that, I don't think that I would understand biomedical engineering as an industry as well as I do now, and the kinds of collaboration and the kinds of hard work and long-term work that go into product development." - Timmy</td>
</tr>
</table>

Undergraduate Research Experience. The 11 participants who engaged with undergraduate research discussed a total of 12 subjective task values (see Table 11). Research participants discussed fewer values that related to developing industry relevant engineering skills. Three codes were identified that could be categorized as utility values in the context of industry skills (i.e., communicating research, problem solving in the moment, and learning course and engineering concepts through application). Unique to the research experience, participants also discussed values related to navigating research and academics post-graduation (i.e., having a mentor, and formal recognition) which were also categorized as utility values. Participants also talked about mentorship and recognition in a way that could relate to attainment values. When participants described the experience as in line with how they perceived themselves they were coded in the attainment dimension and named “gaining confidence through mentorship” and “gaining confidence through recognition”. Other codes that were categorized as attainment values include: “contributing to the field with my work” and “having a community”. Within the codes that mapped to attainment identified in this study, participants mostly described positive experiences; however, one participant described a negative experience related to the code “having a community”. They described the discomfort they experienced in a new research community they joined by saying:

> *“When I first joined the research lab, when I first joined the (BME) lab, it wasn't really awkward. People knew I was an undergrad, people understood that I could do things at some point, I would learn to do things. But now, moving into a different lab, people don't understand that I can do things, and it's just really awkward because I'll ask them for something and they'll be like, "Oh, let me do that for you." But I can be like, "Oh, I know how to do that. It's not that hard. I can do it myself.”* ***– Honey***

Similar to MDE participants’ desire to explore BME industry, research participants expressed a desire to explore BME research, a code which was determined to be related to interest value. Another interest value code was the desire to study a topic they find interesting in general. Interest value codes were the most commonly discussed by research participants (7 participants for each category). While minimal in comparison to the total number of participants, more participants discussed the time investment associated with participating in research than participants in MDE. When talking about time in research, students discussed that the time necessary to do well took away from opportunities to pursue internships or affected grades. Table 12 provides exemplar quotes for each of the categories discussed by undergraduate research students.

Table 11. Research inductive category descriptions.

SVT Dimension	Category	Participants describe…
Attainment Value	*Gaining Confidence Through Mentorship*	the impact a mentor can have on their confidence in their ability to perform work.
Attainment Value	*Gaining Confidence Through Recognition*	the impact gaining formal recognition can have on their confidence in their ability to perform work.
Attainment Value	*Having a Community*	having people they can count on, finding their “group”, or gaining a community.
Attainment Value	*Contributing to the Field with my Work*	the satisfaction of knowing that the work they did contributed to the field.
Cost Value	*It Takes a Lot of Time*	the time it takes to engage in the co-curricular as substantial and potentially conflicting with other priorities.
Interest Value	*Exploring within Research*	the ability to explore their interests in various research fields and see what they enjoy doing in research.
Interest Value	*Studying Something Cool*	the ability to research or learn about something that interests or intrigues them.
Utility Value	*Communicating Research*	the ability to share or communicate the work they through various modes of communication.
Utility Value	*Formal Recognition*	the ability to gain formal recognition for the work they did in order to demonstrate preparedness for future endeavors.
Utility Value	*Having a Mentor*	the ability to ask advice, understand nuance, or hear about experiences from more senior members of the lab.
Utility Value	*Problem Solving in the Moment*	the ability to solve problems, make decisions, or troubleshoot in the moment.
Utility Value	*Learning Course and Engineering Concepts through Application*	the ability to learn by doing or the desire to improve classroom learning by applying knowledge in context.

Table 12. Research subjective task values, corresponding codes, and representative quotes.

Attainment Value:	***Interest Value:***
Having a Mentor “I think I appreciate how awesome my mentor has been and I mean that with 100% honesty. She really believes in me a lot and I think that's helped me a lot...” **- Ernest** *Formal Recognition* “I was kind of told that if I work hard enough and have initiative, that I can get onto a paper, which I feel like that's kind of professional.” **- Cleo** *Having a Community* ‘It sounds kind of cheesy, but especially transferring into engineering, I kind of have had this cloud hanging over my head like, "Oh, I don't know if I belong here. I feel like I'm kind of behind everyone," and it's been very	*Exploring within Research* "I definitely was interested in research and I was kind of at a crossroads at the end of last year, like going into junior year and not knowing what I wanted to do with my BME degree, if I was interested in doing research or industry, or going to grad school… I felt like I couldn't really make the decision without trying it, and I like the idea of just knowing more, learning more, having more skills." **- Sparks**

helpful being like, "No, you're doing something important. You're good at this," and, "This is something you can do and you're good at."'- **Sparks** *Contributing to the Field with my Work* "Honestly, I would tell them that it's very rewarding. Especially if they do research that is in a field that they care about, it feels like you've been taking from this field, learning about this field for a while or have been interested in it for a long time, and to finally be able to do something to push the knowledge boundary of it just a little bit is pretty cool." **- Timmy**	*Studying Something Cool* "Also, if I have things to do, I guess the project will be a success, just in general. Things to do that I'm interested in. That'll make this project a success for me." **- Honey**
Utility Value: *Communicating Research* "I think just making presentations, talking to people, communicating what you learn is a big thing too..." **- Bianca** *Formal Recognition* "A lot of it comes that I want to have experience and just have something to put on my resume, but it also sounds really interesting and it will be really cool to be a part of something that matters, that can, in some way, help people." **- Cleo** *Problem Solving in the Moment* "I guess I feel like I'm less reliant on people. I think if there's a problem, I can figure out how to fix it better. I'm better at just kind of thinking in the moment just because you don't know what's going to happen and there's been days where it's like everything (that) possibly that could go wrong, goes wrong. And it's always the day that my mentor isn't there." **- Bianca** *Having a Mentor* "And also… just having a mentor. I didn't really know anyone who had gotten their PhD in BME before so going through that process is a lot easier. …It's going to be a lot easier to handle because he's gone through it." **- Bianca** *Learning Course and Engineering Concepts through Application* "I would tell them that it's really a practical good experience and that, (there) definitely are connections to things you're learning in class. I didn't really like my material science class, so getting to now work with polymers and like, "Oh no, that this happens because of this property." I think is really cool." **- Samantha**	***Cost:*** *It Takes a Lot of Time* "I guess it's different if you've had internship opportunities… But it's hard because there's not enough time and the only time you can take off of school is summer. But you can only really do one thing per summer. So for me, if I wanted to do my PhD, an internship isn't necessarily in my best interest because grad schools don't really care about that… So if I wanted to do an internship, it would take away from my skills as a researcher. But then if it's grad school and if I want to go into industry… How can I say that I'm ready for that when I haven't had any internship experience?" **- Bianca** "I was really worried that in doing it my grades were going to go down, which is why I didn't do it for so long…" **- Sarah**

Similarities Across Experiences. The most consistent similarity between the two groups of students was their emphasis on utility values and expression of the need to seek out such opportunities to fill a gap in their education. This emphasis could be linked to previously documented student and researcher discussions about the perceived difficulty in getting a job with only a BME bachelor's degree (Berglund, 2015b; Nocera et al., 2018). Evidence that many of our participants share this sentiment is indicated by the few participants anticipating entering the job market with their bachelor's degree (3 participants) as well as in discussions by participants in their interviews:

> *"And I feel like all schools, it's not necessarily Large Midwestern University's degree isn't good. It's more just the BME degree in general is very broad compared to other engineering degrees, which isn't a bad thing. I want to do grad school, so it doesn't really matter but a lot of people come into Large Midwestern University. They're like, "I want to be BME," and then people are like, "You're not going to get a job." That's what you hear from all of the other majors, "You're not going to get a job," or, "Only if you want to do grad school," because a lot of jobs or companies do expect you to have more knowledge which is why you need to do grad school to focus on what you want to do, which is fine for me."* ***– Bianca***

> *"I think that ... I don't know. It's kind of hard to say. I think I've been a bit more pessimistic about it lately just because of what I've been reading about and just hearing from my peers and staff stuff about how hard it can be to get a job in BME. Also, just the realization that I'm halfway through and I still don't feel like I have enough concrete skills to be able to be valuable in a workplace, but I think there is value in the fact that you sort of have a really good baseline for being able to go and do anything within the healthcare industry that you want to do, which I think is really good."* ***– Ernest***

> *"So we just get a lot of introductory material in a lot of different disciplines. So I feel like going immediately out of college, we know a little bit about a lot of things, and that might not help us be competitive in the job market immediately coming out of college, which might make something like another engineering degree a little bit more valuable, if you're just looking at undergraduate work."* ***– Timmy***

Discussion

In this study, evidence was found that students immerse themselves in co-curricular experiences that they believe have utility value for their future career aspirations, but that motivations to participate can also relate to their general interest in the field and their personal connection with the experience. Building skills, creating connections, and getting career advice were all discussed as ways students could improve their career outlooks. More specifically, MDE participants found the opportunities to develop professional skills like communication, leadership, and teamwork along with learning technical content and how to design valuable to their experience. While research participants discussed skill development less frequently than MDE participants in their interviews, they saw utility in the formal recognition they gained through papers and presentations as well as in knowing people who had already navigated graduate school.

Beyond its usefulness for their future careers, participants valued their co-curricular experiences for allowing them to connect aspects of their identity with their major or department (attainment value) and found value in exploring what they enjoyed about the various facets of BME (interest value). Typically, MDE participants talked about attainment value as having a community to which they belonged, or as doing work that helps others as aligning with their personal values. Research participants discussed the interest value dimension of their co-curricular participation more frequently than the MDE participants. They expressed the value of doing research coming from the opportunity to explore their interests, and if they had found that, to do work and ask questions that they found interesting. Students also discussed categories in the cost dimension associated with participating in co-curriculars, though less frequently than interest values. Time was the biggest cost consideration for students who felt they had to make choices between the types of co-curriculars to engage with or the time lost for coursework because of their engagement in the co-curricular.

Finally, the results of this study highlight the important discussion surrounding BME students' perceived difficulty with the job market beyond graduation. Regardless of co-curricular participation, many of the participants anticipated entering industry as a long-term career goal (12 of 14 participants), but discussed the desire or need to specialize before doing so. They linked this desire or need to specialize with the broad interdisciplinary nature of their undergraduate degree. As the evidence of both a perceived and measured gap between BME undergraduate degrees and placement in industry builds, efforts to understand and close the gap are becoming increasingly important (Nocera et al., 2018). Despite this gap, students in our study described their degree as valuable and appreciated the broad exposure to multiple disciplines as a way to explore and keep their career options open upon graduation.

Conclusion. This work was performed at one institution and studied two of the many co-curricular experiences available to students. As such, this work highlights important aspects of students' experiences that warrant further investigation, but cannot account for all of the values students place on their co-curricular participation. Future studies may wish to use these methods to compare and contrast student experiences in other common co-curricular opportunities, such as internships or professional societies. The results of this study indicate that BME students are motivated to participate in co-curricular experiences for their utility value in leading to a career in BME. These findings relate to two important aspects of previous engineering education discussions 1) BME students are concerned that the curricular experience is not sufficient for career placement upon graduation (Berglund, 2015b; Nocera et al., 2018), and 2) some previously studied professional and technical outcomes of co-curricular experiences are motivating factors for student participation (Fisher et al., 2017). While the discussion of cost was minimal in our study, time as a factor for students' decision to participate in co-curriculars warrants further investigation, particularly within a major where students are indicating that co-curriculars are necessary for professional preparation. Beyond the utility value of participation, students discussed the ability to connect how they see themselves as a biomedical engineer and a general interest in the work and non-career related opportunities available to them through their co-curriculars. These findings indicate that students can be motivated to participate in co-curriculars through other means than just the outcomes so heavily studied in prior co-curricular literature.

CHAPTER IV

BME Students' Perspectives on Attaining a BME Degree

Published: (C. S. E. Jamison, Wang, et al., 2021a)

Abstract. *A common perception of BME undergraduates is that they struggle to find industry jobs upon graduation. While some statistics support this concern, students continue to pursue and persist through BME degrees. This persistence may relate to graduates' other career interests, though limited research examines where BME students go and why. Scholars are also pushing for research that examines engineering careers in a broader context, beyond traditional industry positions. This study adds to that conversation by asking: How do BME students describe their career interests and perceived job prospects in relation to why they pursue a BME degree? A qualitative study of BME students was performed at a public, R1 institution using semi-structured interviews at three timepoints across an academic year. An open coding data analysis approach explored career perceptions of students nearing completion of a BME undergraduate degree. Findings indicated that students pursued a BME degree for reasons beyond BME career aspirations, most interestingly as a means to complete an engineering degree that they felt would have interesting enough content to keep them engaged. Participants also discussed the unique career-relevant skills they developed as a BME student, and the career-placement tradeoffs they associated with getting a BME undergraduate degree. Based on these results, we propose research that explores how students move through a BME degree into a career and how career-relevant competencies are communicated in job searches. Additionally, we suggest*

strategies for BME departments to consider for supporting students through the degree into a career.

Introduction

The first BME programs began with engineers who were interested in solving interdisciplinary problems at the interface of engineering, biology, and medicine (Linsenmeier & Saterbak, 2020). This interest in solving interdisciplinary problems links strongly to BME program curricula, particularly at the undergraduate level. BME undergraduate programs across the United States have created curricula that are intentionally broad and diverse, which has allowed students to pursue a wide variety of careers upon graduation (Abu-Faraj, 2008; Linsenmeier, 2000; Ropella, 2003). However, the diversity and breadth of topic areas covered in curricula from program to program has been criticized in relation to preparing students for BME-related careers, particularly for those in industry (Berglund, 2015b, 2015a; C. Jamison et al., 2020). Further, measures related to industry competitiveness, such as co-op or internship opportunities, BME graduate to BME industry job availability ratios, and average BME graduate salaries, show a disadvantage to BME students, and thus, support these critiques (Berglund, 2015a; Gilmartin et al., 2015; Linsenmeier & Saterbak, 2020; Nocera et al., 2018).

While industry-focused studies have indicated that research should explore how BME educators can support students pursing industry positions upon graduation, they often do not consider the many other career interests and pathways of BME graduates (Ropella, 2003). Recent research indicates that BME students are less likely than their peers in other engineering disciplines to pursue engineering industry careers (Gilmartin et al., 2015; J. A. Rohde et al., 2019), which has implications for how universities support student career exploration and placement in BME. Currently, career placement discussions in the BME education literature have focused on careers in industry or placement in graduate-level programs (e.g., medical school, Ph.D. programs, etc.) (A. Huang-Saad et al., 2020; J. A. Rohde et al., 2019), leaving other post-graduate career options such as consulting or clinical BME work underexplored. Given the increasing research that shows BME students are considering career options outside of engineering industry positions, it is important to also understand how those students navigate a BME undergraduate degree.

A greater understanding of why students pursue BME in relation to their career goals can inform how BME programs advertise to attract students, how programs support students in career exploration, and how programs develop strategic partnerships with BME graduate employers. This study employed qualitative methods to understand more about upper-level students' motivations for pursuing a BME degree in relation to career goals, by asking questions about students' perceptions on BME career outlooks and the value they place on pursuing and receiving a BME undergraduate degree. This study extends related work of a recently published paper that found that BME undergraduate students entered their third year with a relatively narrow view of career possibilities and valued opportunities to explore their options through multiple avenues available at the university (C. S. E. Jamison, Wang, et al., 2021b).

Background

Characterizations of BME in the literature often focus on its relationship to both engineering and medicine as well as the need to perform work that integrates knowledge from both disciplines to solve medical problems (Abu-Faraj, 2008; Ramo et al., 2019). The broad scope in how the BME discipline has been defined has allowed BME bachelor's degree graduates to pursue various careers upon graduation. According to one article, BME graduates with a bachelor's degree can secure entry-level engineering positions in medical device or pharmaceuticals, clinical engineering in hospitals, biomaterials or biotechnology sales, academic institutions as researchers, and government agencies (Ropella, 2003). The wide-array of career opportunities available in BME also means that BME professionals are tasked with a wide variety of job responsibilities (Abu-Faraj, 2008). Biomedical engineers may be asked to design instrumentation, medical devices, or software. They may also be tasked with integrating technical knowledge from multiple sources to develop new procedures or conduct research to solve clinical problems (Abu-Faraj, 2008). The breadth of careers linked to BME as a discipline has had a strong influence on what BME curricula has evolved to be today.

The first formal BME programs launched in the 1960s as master's and PhD programs (Linsenmeier & Saterbak, 2020; Ramo et al., 2019). Trailing the development of graduate programs, the first undergraduate programs began in the 1970s and 80s. As more BME undergraduate programs were established, discussions surrounding core courses or competencies also began. Two key initiatives had major impacts on the development of today's BME undergraduate programs. The first major initiative was VaNTH (a team of researchers from Vanderbilt, Northwestern, the University of Texas, and the Health Science and Technology program, which was jointly sponsored by Harvard University and MIT), a National Science Foundation engineering research center focused on BME education. Initially, VaNTH aimed to identify a set of core or foundational competencies in BME to help structure BME curricula across institutions (Abu-Faraj, 2008). The second major initiative was organized by the Whitaker Foundation in 2000 – the first BME Education Summit where the international community sought to develop a common understanding of BME curricula. At the meeting, the group determined that a single 'optimal' BME curriculum was not possible nor desirable. Participants emphasized the need for institutions with BME programs to prioritize the institution's strengths (based on faculty expertise, resource availability, etc.), while also providing rigorous engineering and life sciences education (Abu-Faraj, 2008).

As discussions of BME education have continued, diversity and flexibility in program structure has been a common theme (Ramo et al., 2019). However, while the field moves towards consensus on the need for diverse and flexible programs, two BME educational dilemmas have yet to be settled. First is a question of breadth versus depth in technical engineering content: Is depth (linked with older engineering disciplines like mechanical or electrical engineering) or breadth (linked to more interdisciplinary disciplines like general or industrial engineering (Lattuca et al., 2012)) most beneficial for students entering BME careers? The second dilemma is a question of program orientation: Should BME orient curricula toward practice (often industry positions in sectors such as medical devices, pharmaceuticals, biotechnology, etc.) or research (often academic or government positions) (Katona, 2006)? Understanding the tradeoffs associated with these dilemmas from multiple viewpoints (e.g., university educators, administrators, students, industry stakeholders) has the potential to inform how programs prepare their graduates.

As institutions were first creating BME undergraduate programs, industry careers (e.g., in research and development, design, manufacturing, etc.) were a promising career pathway for graduates because the number of degrees granted was less than the number of available industry careers as a biomedical engineer in the 1970s and 1980s (Abu-Faraj, 2008). However, as more BME programs are being developed and graduate numbers increase, this ratio is becoming less promising for graduates interested in industry jobs. Additionally, research has indicated that the evolution of a BME undergraduate curriculum that is intentionally broad may further limit BME graduates' industry career options upon graduation due to negative industry perceptions of graduate preparedness (Abu-Faraj, 2008; Gatchell & Linsenmeier, 2007; Linsenmeier, 2003; Nocera et al., 2018). Other research attributes these negative perceptions to industry's lack of understanding of what competencies and content knowledge they can expect from BME graduates (Ramo et al., 2019). Acknowledging the diversity of content covered from program to program, some institutions have begun to explore the need to address the industry disconnect directly, citing a need to better market their students and train them to communicate their unique skills (Linsenmeier, 2003). One effort to address this disconnect that has shown particular promise is the development of co-op and internship partnerships, which better connect BME graduates to industry. However, these partnership programs are often labor, finance, and time intensive (Waples & Ropella, 2003). Additionally, these partnerships are contingent on building a relationship between one BME program and a specific company. Evidence that would indicate that this approach can positively impact BME graduates more broadly (i.e., career placement for BME graduates not from a university with industry partnerships) is limited.

While it is important to consider how educators can better support BME students interested in pursuing industry positions given these concerns, recent exploratory work indicates that many BME students may instead or also be considering non-engineering or non-industry career pathways upon graduation (e.g., K-12 education, government, non-profit, etc.) (Gilmartin et al., 2015; Guilford, 2020; Potvin et al., 2018; J. A. Rohde et al., 2019). Some general research on engineering career pathways showed that students who complete an engineering degree program do not always pursue engineering careers. One such study that collected data from engineering majors at two institutions found that completing an engineering degree was not always linked to a commitment to perform engineering work (Lichtenstein et al., 2009). Within the context of BME, Rohde and colleagues found that an interest in BME was negatively associated with the desire to pursue an engineering industry career (J. A. Rohde et al., 2019). Gilmartin and colleagues' exploration of the Academic Pathways of People Learning Engineering Survey (APPLES), found patterns that indicate BME students, when compared to other engineering disciplines like aerospace, chemical, civil/environmental, computer, electrical, industrial, and mechanical, are less likely to pursue engineering industry positions (Gilmartin et al., 2015). They interpreted these patterns as an indicator that BME graduates may view their degrees as bridges to other positions (e.g., medical school or other professional programs). Some other exploratory research indicates that students may pursue BME as a means to combine engineering with other career interests (e.g., clinical careers (Guilford, 2020) or careers that serve or help others (Potvin et al., 2018)).

Research on BME undergraduate student pathways has largely focused on where students go upon graduation, often highlighting industry careers as a key career pathway upon graduation (A. Huang-Saad et al., 2020; J. A. Rohde et al., 2019). Further, the emphasis on industry careers in BME may be limiting graduates' perspectives about possible careers they could pursue upon graduation. Rohde and colleagues support a similar view of engineering education, arguing that earning an engineering degree should be viewed as gaining skills that give students the ability to make a significant and meaningful impact in the workforce, even if they do not enter or persist in a career that is typically classified as engineering (J. Rohde et al., 2020). While research is beginning to understand where students go upon graduation, there is still limited research on why students choose BME, what sort of careers they are interested in, or why they choose to pursue certain careers upon graduation. Research examining students' rationale for pursuing BME can provide important insights on a common understanding of what is possible, interesting, or important for students when choosing a major and subsequently a career upon graduation. These insights could inform program advertisements, career mentoring efforts, or company co-op and internship partnerships within a department. This study aims to contribute to that work by examining a set of BME student experiences in depth, offering suggestions for department-level programming and future research in this area.

Study Design

This study was guided by the following research question:

How do BME students describe their career interests and perceived job prospects in relation to why they pursue a BME degree?

We leveraged a qualitative interview approach to address the research question of this study. Qualitative methods were beneficial for this study because the goals of the study aligned with the strengths of a qualitative approach to data collection and analysis (Leydens et al., 2004; Merriam, 2009b). Qualitative research is flexible and allows a researcher to adjust their research approach to align with the ongoing research process (e.g., adding or adjusting research questions, adding interview questions, adjusting analytical approach) (Case & Light, 2011). This approach to research was also relevant in this study because the refinement of questions allowed for the addition of a research question to the project which explored a phenomenon that was not originally within the scope of the interviews' goals. Identifying discussions about career prospects and BME degree value early in the study allowed us to explore a research question that was potentially important to understanding the degree and career perceptions of BME students.

The qualitative interview data in this paper were collected as part of a three part, year-long longitudinal study that examined the experiences of upper-level BME students in co-curriculars at a large R1 university and was determined as exempt by the institution's review board (HUM00168130). One goal of the interviews was to understand BME students' professional development through co-curricular engagement (which is outside the scope of what is reported here). However, this goal to investigate co-curricular engagement affected our recruitment strategy of inviting students to participate in interviews who were engaged in one or both of the following co-curricular settings: a multi-disciplinary design team aimed at solving BME problems and undergraduate research. This participant sample also allowed us to investigate students' decisions to pursue a BME degree and their plans for their future careers.

During preliminary analysis of the first interviews, the first author noticed that students' comments seemed to relate to why they pursued their degree in relation to future careers. Follow-up questions to probe BME degree and career perceptions more directly were then added to the subsequent interview protocols. Refining (by adding or adjusting) research questions is a common approach in qualitative studies, which stress ongoing data collection and the interconnectedness of the multiple stages of research (e.g., literature review, research questions, methods selection, data collection, data analysis, and write up) (Case & Light, 2011).

Institutional Context. The institution where data were collected was a large, research-oriented, public university in the Midwest United States. At the time of article submission, the enrollment in the BME program was approximately 400 students. Of those enrolled, approximately 56% of them identified as female and 16% had a historically marginalized racial or ethnic identity in engineering. The BME students in this study selected one of three concentrations to pursue within the major: bioelectrical (~11% of students), biochemical (~58% of students), or biomechanical (~31% of students), however, the program recently transitioned to a broader track-based system for concentration areas. To complete their concentration, students in this study selected 14 concentration specific credit hours of 128 total credit hours required to complete a BME degree. Recent data collected from an alumni survey indicates that approximately 26% of graduates enroll in medical school, 45% go into industry or government jobs, while the remaining 29% pursue other career pathways (e.g., consulting, social work, other post-secondary education, law, etc.). Due to the timing of the study (in the 2019-2020 academic year), the final interviews occurred after classes had moved to a fully remote format in response to the COVID-19 pandemic.

Participants. A set of participants were identified for the full study based on their academic standing (i.e., third-years) and participation in co-curricular activities of interest (criterion-based, purposeful sampling) (Merriam, 2009a). To expand the participant pool, snowball sampling was employed by asking participants to identify others meeting the criteria who might be interested in participating (Merriam, 2009a). In studies where potential participants are difficult to identify or gain access to, snowball sampling is a common strategy to reach participants (Hesse-Biber, 2017). Snowball sampling was employed in the full study to identify potential participants in the targeted co-curriculars, and especially those in undergraduate research, where students can participate in multiple capacities that are difficult to track at a departmental level (e.g., for credit, through university programming, for pay, or as a volunteer). Some researchers have critiqued snowball sampling based on the possibility of recruiting a sample that is not representative of the population of interest (Hesse-Biber, 2017). In consideration of these concerns for the research question posed in this study, saturation (i.e., redundancy in the themes generated) was used as an indicator that the purposeful, snowball sampling approach was sufficient to explore the research question as it was posed for BME students in this particular context (Merriam, 2009a).

Overall, the study recruited 14 BME undergraduate students at the beginning of their third year. Fourteen participants is within the range considered to be a typical sample size for a qualitative study, which aims for depth of understanding, not generalizability (Hesse-Biber, 2017; Merriam, 2009b; Saldaña & Omasta, 2018). Participants varied by self-reported gender, race and ethnicity, and intended concentration (summarized in Table 7). To protect the confidentiality of participants, direct quotes have been given a pseudonym selected by the participant followed by the interview number in which it took place. As an example, the first interview completed by Timmy (pseudonym) is referred to as TimmyI1 within the context of this study.

Interviews. A series of three 45 to 90 minute semi-structured interviews were conducted over the academic year by the first author, a BME graduate student, at the beginning of the participants' first semester (I1), the end of the first semester (I2), and at the end of the second semester of their third year (I3). Interviews were recorded and transcribed verbatim, with identifiable information redacted following transcription. All 14 participants completed I1 and I2. Thirteen participants completed I3.

As part of the larger study goal, semi-structured interviews were conducted to explore student perceptions of their professional development through their participation in co-curricular activities. The particular advantage of semi-structured interviews for this study was the flexibility of the questions asked. Typically, in a semi-structured interview, the interviewer asks all participants a series of questions, which facilitates comparisons across participants and time points; however, the interviewer also has flexibility in the interview to ask follow-up questions to further explore participants' views on a topic (Leydens et al., 2004). Follow-up questions about participants' perceptions of the BME job market were added during the first interviews to explore the research question posed in this paper. These questions were then added to the interview protocol in I2 and I3. The discussions from those questions were extracted from the interviews and analyzed for this study.

Data Analysis. Interview sections that mentioned students' views of the BME degree or their perspectives on career placement were selected from the interview transcripts and compiled into NVivo 12, a software commonly used to organize and label qualitative data as part of the analysis process (*NVivo Version 12*, 2018). The first two authors read through the interviews, identifying common areas of student discussion in the data, and agreeing on three foci (personal value, unique skills, and perceptions of career placement) to analyze in more depth. This process of reviewing the data and identifying broad topic areas to explore more in depth aligns with holistic coding approaches in qualitative data analysis [30, p.166-168]. Then, the first author analyzed the focus areas inductively, identifying themes in each. A values coding approach, which applies codes that aim to represent individuals' perspectives, was used to inform the identification of the themes presented [30, p. 131-136]. This approach was helpful in identifying the values and beliefs students had about pursing a BME degree and subsequent career. The first two authors discussed these themes to reach consensus (Hsieh & Shannon, 2005). Themes could be mentioned multiple times by a participant within one interview; however, in looking for patterns across time as presented in the results section, a theme was counted only once per interview. This strategy allowed the research team to look at how many participants discussed a theme at least once throughout the three interviews as well as look at how consistently themes were discussed by students when asked the same questions over time.

Addressing Qualitative Research Quality. One approach to establishing the quality of a qualitative research study, specific to engineering education research, is a process-oriented framework that addresses validity in all stages of the research study (Walther et al., 2017). The framework describes five validation constructs (theoretical, procedural, communicative, pragmatic, ethical) that pose questions for researchers to consider to achieve research quality from the making data to the handling data stages of a study (see Table 13 for descriptions of each validation construct). Throughout this study, the researchers engaged in reflective practices to ensure quality and to improve the reliability of the research process. Efforts that align with each of the validation constructs are also included in Table 13. By aligning conversations of quality with the framework developed by Walther and colleagues, qualitative researchers can clearly communicate the steps taken throughout the research process to ensure reliable, high-quality research (Walther et al., 2017). In doing so, they can also improve the understanding of quality qualitative research in the broader engineering education community.

Table 13. Five types of process validation in qualitative engineering education research (Walther et al., 2017).

Validation	Description	Study Efforts
Theoretical	concerns the fit between the social reality under investigation and the theory generated.	The interviewer noticed discussions by participants about job prospects and concerns about employment in the first interviews of the full study. In order to probe these ideas further, the interviewer added questions about these perceptions in Interviews 2 & 3 in order to gain a deeper understanding of the phenomenon observed.
Procedural	concerns features of the research design that inherently improve the fit between the reality studied and the theory generated.	The students in this study were recruited for a project on professional development through co-curricular experiences; however, during data collection an additional research question was developed for this study to explore BME students' career perceptions more broadly. When adding the research question, the research team reflected on the match between the study sample and institutional population, considering what claims could be made from the data throughout analysis. In looking at participant responses to the same questions across time, the research team was able to gain insights into perceptions that were frequently discussed which could indicate the relative importance of themes in the data.

Communicative	concerns the integrity of the interlocking processes of social construction with the relevant communication communities.	By providing a thorough description of the study context and participants, the research team aimed to provide other researchers insights into if the work would be transferable to their context. In qualitative research, rich description is a common practice to allow other researchers to determine the relevance of the findings in their own context (Borrego et al., 2009). Additionally, examples of how participant responses were coded were provided to increase the transparency of the analysis process, which allows readers to determine if they agree with how data were organized and analyzed.
Pragmatic	concerns the compatibility of theoretical constructs with empirical reality.	Pragmatic validation was considered in the analysis and interpretation stages of the research, where the research team carefully considered the conclusions that could be drawn from the context of this study. As such, discussion of results focuses on findings that have not been presented on the topic previously and suggests future research based on each of the themes presented in the results.
Ethical	concerns aspects of integrity and responsibility throughout the research process.	Data analysis and interpretation stages engaged researchers at multiple levels of their BME careers (a second-year undergraduate student who recently declared BME, a fourth-year BME PhD student, and a BME faculty member with industry experience). In doing so, conversations during the analysis phase addressed the relevance and accuracy of the themes presented from multiple perspectives.

Results

Three common areas of focus were identified in participants' discussions about career prospects and the value of their degrees. The first focus related to the personal value participants placed on their degree. In particular, participants described values beyond how the degree related to attaining a future BME career (i.e., how they described the value of the degree, regardless of their intention to stay in a career they perceived as BME). Focusing on the career placement value participants attributed to the degree, the second focus area identified some unique skills participants felt they had gained by pursuing a BME degree. Themes in the third focus area also related to career placement for students, identifying what participants described as perceptions of BME graduates. Participants discussed negative interpretations of these perceptions as possible barriers to a successful BME career search because of their choice of major; however, participants also frequently cited ways to positively interpret these perceptions during a career search.

The Personal Value of an Undergraduate BME Degree. Participants frequently described reasons for pursuing BME that did not directly relate to BME career placement (i.e., getting a job that they considered to be a BME career). Instead, the authors identified themes that captured how participants perceived how they personally could find value in the degree even if they were questioning their interest in pursuing what they thought a BME career was. These themes related to how the status associated with the degree (either engineering in general or the program at their institution specifically) and its curricular content played a role in their persistence in the degree. Three themes related to these personal values emerged from a deeper analysis of the data. These themes indicated that, beyond the value related to BME career aspirations, students also valued their BME degree for the following reasons:

> *Personal Value 1:* Engineering is a valuable degree for pursuing a career in many fields.
> *Personal Value 2:* The university I go to is well known for BME, which will help me in my future career goals.
> *Personal Value 3:* The connection to biology or improving human life made engineering content interesting.

Half of the participants mentioned that an engineering degree in general (Personal Value 1) was valuable for their future goals in at least one interview, regardless of their current career aspirations. This indicated the relatively high value participants in this study place on engineering degrees in general. A similar pattern concerned how participants discussed the value associated with a BME degree from the specific institution they attended (Personal Value 2), specifically as it related to prestige or recognition of the particular university where the study took place. A smaller number of participants overall discussed the third personal value theme, the value of BME subject matter in keeping them engaged in an engineering field, in at least one interview (n =5); however, the highest number of participants consistently named curricular content as valuable across all three interviews (n=3). Table 14 shows example quotes of each theme along with the number of participants who discussed the theme in at least one interview or across all three interviews.

Table 14. Examples of participants' Personal Values of having a BME degree.

Theme	Example Quote	1+ Mention	3 Mentions
Personal Value 1	*One, obviously it's a bachelor, engineering degree. That's really good. And it's within the health care… I think that longer term when it comes to how it's going to look on paper for my career, I think that it's not really going to matter too much between if I got a BME degree or if I got an IOE degree for my undergrad. Because I think that's been the main thing that I've been thinking about is like "Man, did I sort of waste*	n = 7	n = 1

	my time doing this BME degree when I'm ending up going more down the operations route and doing sort of IOE type stuff?" ***– ErnestI3*** *[talking to a mentor about completing the BME degree and pursing nursing after completion or switching majors in their third year] And he [the mentor] said that part of the value in finishing an engineering degree instead of switching to nursing – at that time, cause that's what I was talking about just changing majors – that it shows that you can just take a lot… and that you can weep over the hardest problem and then come back to work the next day. And that's kind of what's been pulling me through this because I'm not really sure. I think that for where I'm headed, I think that my degree shows that I have some ability to understand technical problems.* ***– SarahI3***		
Personal Value 2	*I feel like it's like an engineering degree on its own from [Study's University] is super valuable. I think people see that and they know how the curriculum is and just how much work it is and how well you have done to get that in the first place. I don't really know about specifically the BME degree I would assume it's similar, we're top 10 consistently in BME, so I'm assuming that would give me an edge in grad school.* ***– BiancaI2***	n = 6	n = 1
Personal Value 3	*I think it's really important to study something that you're genuinely interested in. I knew that I wanted to do engineering. Engineering itself is such a hard curriculum, I honestly don't think I could get through four years of, because hearing BMEs might not be valued as much as a mechanical engineer or whatever for a mechanical job, I genuinely don't think I would have been interested enough in those classes without having the biology aspect of it and helping people aspect of it pushing me through hard stuff. I think by liking my classes and liking what I'm doing, that just makes me a better possible employee too.* ***– SparksI1***	n = 5	n = 3

The Unique Skills Gained Through a BME Degree. When asked to discuss the value of their degree when applying for a job, participants named four skills that they thought made them highly qualified for jobs in BME. Participants discussed the kind of work they thought they would be performing in teams, across disciplines, and in the context of problem solving. Based on those characterizations of general BME work, participants described biomedical engineers as having the unique ability to:

Unique Skill 1: Understand how human biology impacts a problem.
Unique Skill 2: Communicate across the disciplines involved in problem solving or definition.
Unique Skill 3: Bring together multiple disciplinary perspectives to solve a problem.
Unique Skill 4: Be open and accepting of the value of collaboration when problem solving.

Participants discussed the ability to understand how human biology can impact a problem (Unique Skill 1) and to bring multiple disciplinary perspectives together (Unique Skill 3) most frequently of the four skills identified. Table 15 shows example quotes of each skill along with the number of participants who discussed that skill in at least one interview or across all three interviews.

Table 15. Examples of participant claims of Unique Skills gained through a BME degree.

Theme	Example Quote	1+ Mention	3 Mentions
Unique Skill 1	*I know [my BME degree] would be valuable to a good team of, just a variety of engineers, just because, as I mentioned earlier, we do have a lot of the similar skills as other types of engineers, but we do have a deeper understanding of biological processes, and how to apply the basic engineering to the human body, which is obviously essential.* ***– MargotI1***	n = 8	n = 3
	I'd probably tell them that I understand how to work on the human body applications of various... I can't say things. Just various products, so drugs, prosthetics, or just things that help the body from the outside, can help with devices that take measurements from the body. Yeah. Or just engineering other things to mimic the body. ***– HoneyI1***		
Unique Skill 2	*So, I think BME is a mix between a lot of different majors. In order to be good at BME, you need to be able to have a wide range in knowledge. You're not going to be the most depth at a certain topic, but you have the breadth to communicate between electrical engineers, mechanical engineers on the goal of a project.* ***– DetroitI1***	n = 8	n = 0
Unique Skill 3	*I think that biomedical engineers have… a very good ability to draw together ideas and concepts from different disciplines, and apply to engineering design and innovation. Just because while other engineering disciplines, yes, they have to draw together different things that they learn in discrete courses. BMEs are really working at the intersection of human life and engineering. So, I think that the practice that we get in our education and through [co-curriculars], help us to use skills in drawing together interdisciplinary fields, not just for BME purposes, but in general, just like blurring the distinct lines that are often drawn between different fields.* ***– TimmyI1***	n = 12	n = 5
Unique Skill 4	*Just the experience, not only in the classes that are offered in BME, of being interdisciplinary themselves, but also the opportunities of working with other disciplines and understanding the key core concepts, in working with them and hopefully in the actual physical sense of building something or creating something or programming or CADing something. That exposure and experience gives BMEs a lot of advantage in working in interdisciplinary teams and contexts.* ***– AJI2***	n = 3	n = 1

The Perceptions of a BME Degree that can Affect Career Placement. When discussing the difficulties that BME graduates face when applying for BME jobs, students often described perceptions of a BME degree that could lead to difficulties securing a job. These perceptions related to competition with other engineers who apply for the same jobs (e.g., mechanical, electrical, and chemical) (Perception 1), the disciplinary breadth of their required coursework (Perception 2), and the breadth of possible careers that BME graduates can enter (Perception 3). When discussing these perceptions, participants also frequently reframed the conversation by naming ways they might interpret them more positively. For example, students discussed misconceptions of what BME graduates know and the perception that it is easier to teach mechanical engineering (ME), electrical engineering (EE), or chemical engineering (ChE) graduates biology concepts than to teach BMEs deeper technical skills. However, they also discussed strategies for competing with other engineers by emphasizing BME graduates' communication skills, ability to work on interdisciplinary teams, and understanding of the human aspects of a problem in interviews. Similar pro and con discussions occurred when students talked about the breadth of their curriculum and career options upon graduation. Students' descriptions related to this focus area often intertwined multiple themes within the same section of their discussion. For example, in Interview 2, Bianca described the value of her degree like this:

> *I don't know, the BME degree in itself […] in general is still new. And that people don't really know what it means to be BME unless you're in BME, and so I feel like that makes it less valuable than [a] mechanical engineering degree […] I feel it's going to get better […] as people get more familiar and the field is going to blow up, I think but as of now, I just feel like that's why people do grad school because it's you need to be able to focus on something […] to be like, "Yeah, I'm an expert at this, hire me because I know everything about this," versus like, "I'm BME," I know a lot about a lot of different things you can teach me things I could work for you whatever, but it's... I feel like having a grad degree in BME is more valuable.*

When prompted further to describe the value in the workplace this participant added:

> *I feel like if you compare a BME degree to aerospace or something it's like where can an aerospace engineer work? You can work on planes or on rockets, that's it. Versus, BME you can work, consulting, tech companies, I didn't even know Apple hires BMEs, they hire BMEs it to work on fitbits and stuff, Google, Nike, all these things that you wouldn't think of that I've learned and I'm sure it's not like you're competing […] a mechanical engineer can't do the job of a BME In Apple, you can't. Those are things that are specific to the BMEs and I think that's pretty valuable […] I think just it's broad enough that it gives you options.*

The participant then went on to discuss what makes BME students unique by saying:

> *I feel like we have to take a lot of random prerequisites that diversify our way of thinking, it's not just re-engineering stuff, the fact that we have to take orgo, biochem, all of the calcs […] We are prepared for med school*

because we can do the memorization, brute learning kind of thing that [other college within the university] kids do, but also we have that logic way of thinking […] BMEs I know do really well at orgo. And [other college within the university] kids are like, "That's our hardest class, oh my God it's awful," but it's just because we're good at pattern recognition, we're good at... It's not memorization, it's just like, oh, you see this and oh, the next thing would be this and […] it's more the way that engineers think. I think that's what we have, but we also have the random memorization facts thing that, I feel like other majors wouldn't have […] I just think the chem stuff is just random memorization that you wouldn't necessarily get as an other engineer that... Just valuable knowledge, I guess on other things that are more applicable.

In this example, Bianca discussed both positive and negative interpretations of the perception that BME graduates compete with other engineers for BME jobs, but she also added ways to frame her degree positively that related to perceptions of breadth at a cost of depth in disciplinary knowledge and breadth in possible career paths upon graduation. During the interviews, study participants shared both negative and positive perceptions about how their BME undergraduate degree might affect their career placement. These discussions were often complex and interrelated. As such, the research team developed a set of statements, presented in Table 16, that represent these perceptions. Positive interpretations of the perceptions are presented in the right column and negative interpretations are presented in the left column. These statements are not direct quotes from participants but rather the researchers' interpretations of different kinds of perceptions shared by participants.

Table 16. Participant perceptions of how a BME degree can affect career placement.

Perception 1 Biomedical engineers compete with other engineers for biomedical engineering jobs.			
(-) It is easier to teach biology to an engineer than technical engineering content to a biomedical engineer.		(+) Biomedical engineers bridge the gap between disciplines on interdisciplinary teams because they are able to communicate between them.	
(-) People do not know what a biomedical engineer is taught so they have unrealistic expectations.		(+) Biomedical engineers have a better understanding of the human biology side (patients, other stakeholders) of a problem.	
1+ Mention (n = 8)	3 Mentions (n = 0)	1+ Mention (n = 6)	3 Mentions (n = 0)
Perception 2 Biomedical engineers learn a breadth of disciplinary concepts, but none in depth.			
(-) It is difficult to demonstrate how a biomedical engineer's broad exposure aligns with a specific career path.		(+) The broad curriculum gives a biomedical engineer freedom to tailor their experience to specific interests (e.g., courses, co-curriculars).	
(-) Broad disciplinary exposure requires many introductory classes and pushes back exposure to classes that teach technical, career relevant skills.		(+)The subject matter relates to human or biology problems which keeps some students interested in pursuing engineering.	
1+ Mention (n = 9)	3 Mentions (n = 0)	1+ Mention (n = 9)	3 Mentions (n = 0)

Perception 3 Career options for biomedical engineers is very broad.			
(-) There are so many career options for a biomedical engineer. Where do I start?		(+) I came in with a perception that BME career options are broad, but that perception has broadened further as I progress.	
(-) If I try to focus on one part of BME to be more aligned with a career, what happens if I dislike it?		(+) Focusing on a specific sector of BME careers with courses and co-curriculars makes one more competitive.	
		(+) A BME degree gives you flexibility after graduation to try a career path and if you do not like it, try something different.	
1+ Mention (n = 4)	3 Mentions (n = 0)	1+ Mention (n = 11)	3 Mentions (n = 2)

Discussion

In this study, the research team explored how students discussed the value of their BME degrees and their motivations for pursuing BME. We found three areas of focus in participants' discussions: 1) personal value of the degree, 2) unique skills BME graduates have, and 3) perceptions of BME graduates. Students found the degree valuable for personal reasons, not necessarily linked to attaining BME careers, but more related to their persistence in the degree. They described a set of professional skills they felt were important and unique to BME graduates, and they discussed the how they felt earning a BME undergraduate degree was perceived. Based on the themes identified in the three focus areas and the literature reviewed, implications for changes in practice and suggested research topics that warrant further investigation are proposed.

The Personal Value of an Undergraduate Degree. Participants indicated that they valued BME because it allowed them to study something they find important or interesting within engineering. This finding proposes a potential motivation that draws students to BME apart from industry-centric, career-related motivations frequently studied in engineering. Apart from Potvin and collaborators' work (Potvin et al., 2018), very few studies have explored these motivations in BME students. Understanding this motivation and identifying other non-career related motivations for pursuing BME can contribute to recruitment and retention efforts in BME programs. Additionally, all three of the participants who consistently mentioned this motivation had at least one marginalized identity within engineering (further identity details omitted to protect participants' identities). Given that BME has been recognized for attracting more diverse students, particularly women (Linsenmeier & Saterbak, 2020), this finding warrants distinct examination in future studies. Future research in this area should not only focus on how BME attracts diverse students, but given recent research that indicates that students may not pursue engineering jobs upon graduation (Gilmartin et al., 2015; Lichtenstein et al., 2009; J. A. Rohde et al., 2019), studies should also examine patterns in how diverse students exit the degree program, paying particular attention to what careers they pursue and why.

The Unique Skills Gained Through a BME Degree. Participants viewed the unique skills of BME graduates as linked to problem solving, particularly their ability to: 1) understand the human biology context of a problem, 2) communicate across disciplines, 3) bring together multiple disciplinary perspectives, and 4) be open and accepting of the value of collaboration. Other research has examined the perceptions of what skills other stakeholders (e.g., industry employers, academic employers, educators) expect from BME students in an effort to inform curricula (Linsenmeier & Gatchell, 2006; Linsenmeier & Saterbak, 2020; Rivera et al., 2020; White et al., 2020). An article by Rivera and colleagues compared the desired skills of academic and industry employers finding that both academic and industry sectors emphasize professional skills more than technical skills, BME conceptual knowledge, or specific experiences (Rivera et al., 2020). In looking at specific professional and technical skills mentioned by the interviewees in their study, they also found that the expectations did not align between industry and academic stakeholders and suggested that more opportunities should be created for students to develop the variety of professional and technical skills needed to be successful in BME. Given that the skills identified by the students in this study align partially with those identified in previous academics' efforts (Abu-Faraj, 2008; Linsenmeier & Gatchell, 2006; Linsenmeier & Saterbak, 2020; Rivera et al., 2020; White et al., 2020), but do not comprehensively cover them, future research may wish to examine how students determine what they consider career-relevant skills or how departments can help students communicate how the unique skills they develop as a BME student align with specific employer priorities.

The Perceptions of a BME Degree that can Affect Career Placement. Students' expectations about exploring career options post-graduation included: 1) Biomedical engineers compete with other engineers for BME jobs, 2) Biomedical engineers learn a breadth of disciplinary concepts, but none in depth, and 3) Career options for biomedical engineers are very broad. These perceptions were highly aligned with longstanding discussions in BME education (Berglund, 2015b, 2015a; Nocera et al., 2018). Given the persistence of these views in the discipline, researchers and educators should consider different approaches to understanding and addressing the problems students encounter with how BME is perceived as it relates to career placement. Two questions to consider are:

1. *What resources, educational opportunities, workshops, etc. should be incorporated into the BME undergraduate experience to help BME students market themselves for a career? What might those additions look like (e.g., length, format, etc.)?* One example of an addition universities have implemented with success is the co-op and internship industry partnerships described by (Waples & Ropella, 2003), but resources for students who cannot participate in internships or do not aim to pursue industry should also be considered in the development of career-related educational efforts.
2. *How could departments facilitate opportunities for undergraduate students to explore careers outside of those currently considered conventional for BME graduates (e.g., industry, medical, or other graduate school)?* In another article, career discussions from the same participants interviewed in this study were explored. Findings from that study give preliminary insights on what career exploration opportunities looked like for students at their university (C. S. E. Jamison, Wang, et al., 2021b).

Finally, in looking at how educators might help students positively interpret the perceptions of BME graduates, it may be helpful to use the interpretations that students in this study used to reframe the perceived barriers to BME career placement as summarized by the research team in Table 16. Despite acknowledging the negative stereotypes of a BME undergraduate degree, participants were able to communicate how that stereotype could also be beneficial in a professional setting or in the job search process. Educators or advisors may use these reframing strategies to facilitate conversations with students struggling with a job search.

Limitations. In most cases, qualitative research does not aim to be generalizable (Hesse-Biber, 2017; Merriam, 2009b), and as such, the findings in this study may not encompass all of the perspectives of the general BME student population. Instead, this work contributes to educators' and researchers' understanding of the BME student experience in a different way. The in-depth discussions examined over time in this study allowed for the identification of common student experiences that had not been explored in previous research, make recommendations about practices that could benefit students' career exploration experiences in BME, as well as make recommendations for future research based on the patterns identified in this exploratory work. The students interviewed in this study represent a subset of students in BME programs, but the commonalities identified across their experiences are worth investigating in future research and other contexts. Research that includes students in different stages of their degree program (e.g., first year, second year, graduate-level students, etc.), that expands representations of students of different racial or ethnic backgrounds, and that includes different institutions might map to the three focus areas identified in this study, verifying these experiences in new contexts. This research could also identify additional patterns of discussion that further expands the understanding of students' perceptions of a BME undergraduate degree. Most notably, further exploration of the experiences and perceptions of BME students who hold marginalized identities is needed to understand their perceptions of the personal value of the BME degree.

Conclusions. In this study, the reasons for pursuing their degree and the career perceptions of students with a BME undergraduate degree were explored through interviews of a cohort of third-year BME students. Results of this study suggest future research to explore how students move through BME programs in relation to career paths, how students and programs communicate the unique skills students develop through BME undergraduate programs, and how programs can help students explore career opportunities in the field.

CHAPTER V

BME Students' Career Exploration Perspectives

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Abstract. *Historically, BME undergraduate programs have been designed to expose students to the broad spectrum of knowledge required to adequately address problems in engineering and medicine. While students' resultant knowledge base has allowed for flexibility in the careers that undergraduate biomedical engineers can enter, many BME students also believe that the broad curriculum may lead employers to perceive them as underprepared to enter industry positions upon graduation. Recent studies have validated this concern, as BME students report fewer co-op and industry internship placements pre-graduation, enter the job market with fewer available jobs seeking BME graduates, and receive lower average annual salaries than other engineering disciplines. Despite the challenges, students continue to pursue and persist through BME undergraduate degrees. If the perception is that their options are limited in industry, it is important to identify and understand the careers that BME students consider pursuing. To explore what BME students perceived as possible for a career upon graduation, this study examined changes in BME students' career perceptions over the course of a year of their undergraduate program. Fourteen (14) undergraduate BME students were interviewed three times over the course of their third year at a large R1, public university. A qualitative analysis identified patterns of change at the individual and group levels. Findings indicated that most participants' initial view of possible careers in the field was narrow. Over the course of the study, some participants changed their view of career possibilities; for those who had not yet decided on a* *career, concrete exposures to possible BME careers contributed to more optimistic career outlooks. Suggestions for future research to more broadly understand BME students' career exploration are also presented.*

Introduction

BME degrees are often advertised as a means to pursue many career pathways upon graduation (Ropella, 2003); however, at the same time, their curricula has been criticized as being too broad and not deep enough to prepare students adequately for industry work (Berglund, 2015a, 2015b; C. Jamison et al., 2020). Studies have explored these criticisms by looking at measures of industry competitiveness, such as co-op and internship placement pre-graduation, ratios of BME graduates to BME industry jobs, and average annual salaries of BME graduates. Reports indicate that BME students have fewer co-ops and internships pre-graduation (Nocera et al., 2018), enter the job market with fewer job opportunities (Berglund, 2015a; Linsenmeier & Saterbak, 2020), and receive lower average annual salaries than other engineering disciplines in industry (Berglund, 2015a; Gilmartin et al., 2015; Nocera et al., 2018).

While enrollment and graduation rates in BME undergraduate programs continue at a steady pace (Linsenmeier & Saterbak, 2020), knowledge about what students' career aspirations are, where they go upon graduation, and why, is limited. Some preliminary data collected from alumni of one large, R1 institution with a BME program indicated that while a good proportion of students (40%) may enter BME considering pathways like medical school or graduate school, many of those students (from 17% entering the degree to 45% upon graduation) end up pursuing industry positions after graduation (A. Huang-Saad et al., 2020). Given the previous figures on students' career plan changes between entry and graduation, as well as the stigma that BME bachelor's degree graduates experience with industry career placement barriers, more research is needed to understand students' perceptions of BME industry career pathways, particularly at a later stage in the degree. Understanding these perceptions can help inform how BME programs are advertised, how programs help students explore industry career options, and how programs strategize partnerships with industry employers. This qualitative study used an exploratory approach to examine third-year students' perceptions of an undergraduate BME degree as a means to pursue a career upon graduation, with particular analytical focus on career pathways. Most immediately, results can be used to make recommendations for how to better serve the needs of students at the institution where the study was performed. More broadly, this exploratory work proposes important areas for future research that can help educators understand how BME students' perceptions of the field change between their enrollment and their successful entry into a career.

Background

In the scholarly literature, BME is often viewed as a discipline characterized by its ties to both engineering and medicine, as well as the necessary work performed across those disciplines, to integrate knowledge and solve medical problems (Abu-Faraj, 2008; Ramo et al., 2019). With such a broad definition, BME is applicable in many professional contexts. For example, when tasked with describing what a BME does, one author posed a counter question: "What don't biomedical engineers do?" [1, p. 23]. BME bachelor's degree graduates can work in entry-level engineering positions in medical device or pharmaceutical companies, clinical engineering positions in hospitals, sales positions for biomaterials or biotechnology companies, research positions at academic institutions, and positions in government agencies (e.g., the FDA) (Ropella, 2003). With further education, those with BME undergraduate degrees have also gone on to work as physicians, business managers, patent attorneys, physical therapists, professors, research scientists, teachers, and technical writers (Ropella, 2003). With a wide array of possible careers, BME professionals must be prepared to perform a wide variety of job requirements (Abu-Faraj, 2008). Within their day-to-day tasks, a BME practitioner may be asked to design instruments, devices, or software, integrate technical knowledge from multiple sources, develop new procedures, or conduct research needed to solve clinical problems (Abu-Faraj, 2008).

Historically, as the number of BME undergraduate programs grew, BME program directors viewed industry positions as a promising employment option for undergraduates. Researchers and educators cited positive statistics for the number of degrees compared to the number of industry jobs (i.e., involving the design, manufacturing, regulation, and sale of products and services in the biomedical sector) available for biomedical engineers in the 1970's and 1980's (Abu-Faraj, 2008). However, as more programs have developed and the number of graduates has increased, the ratio of graduates to the number of industry job openings has become less promising (Linsenmeier & Saterbak, 2020). Further, research on student job placement shows that the history of BME program development as intentionally broad and unique to each institution's faculty strengths (Abu-Faraj, 2008), may have had a negative impact on industry's perceptions of BME graduates, limiting BME student industry career placement upon graduation (Abu-Faraj, 2008; Gatchell & Linsenmeier, 2007; Linsenmeier, 2003; Nocera et al., 2018). These studies indicated a disconnect between industry desired skills and the training received by BME graduates (Abu-Faraj, 2008; Rivera et al., 2020). Other research discussions proposed that the lack of consistency in what is taught across BME programs has contributed to industry's limited understanding of the knowledge and competencies they can expect of BME graduates (Ramo et al., 2019). In acknowledgement of these issues, some programs have expressed a need to better market their students' abilities and prepare students to communicate their skills to address this perceived disconnect (Linsenmeier, 2003).

In examining industry jobs available to students within the BME field, it appears that BME industry placement with an undergraduate degree is difficult. Despite concerns surrounding industry job placement associated with a BME degree, students continue to pursue and graduate with the undergraduate degree (Linsenmeier & Saterbak, 2020), which may be related to other motivations students have for pursuing BME. Research on engineering career pathways has indicated that completion of an engineering degree does not necessarily mean that students will pursue engineering work. In particular, a study of engineering students across disciplines at two universities showed that students who complete an engineering major are not necessarily committed to performing a traditional engineering job (Lichtenstein et al., 2009). Along similar lines, a study by Rohde and colleagues (J. A. Rohde et al., 2019) indicated that an interest in BME was negatively associated with entering an engineering industry career. Further, using the Academic Pathways of People Learning Engineering Survey

(APPLES) dataset, Gilmartin and colleagues (Gilmartin et al., 2015) also found patterns that indicate that BME students are less likely to pursue engineering industry positions when compared to other engineering degrees, interpreting their results as evidence that perhaps BME graduates see their degree as a bridge to other positions (e.g., medical school or other graduate schooling). While research suggests that not all BME graduates wish to enter industry careers, other motivations students have for pursuing a BME undergraduate degree are relatively understudied in the current literature. Some preliminary research indicates that BME may be attractive to students as a way to combine engineering with their other career interests (e.g., clinical careers (Guilford, 2020) or a career that allow them to help others (Potvin et al., 2018)).

Given the complexity of BME industry career placement upon graduation, institutional efforts to improve students' understanding of BME as a career should focus on improving communication of their career options upon graduation, including careers that may not be perceived as traditional engineering positions. Rohde and colleagues support a similar strategy in approaching engineering education more broadly, stating that research in engineering education frequently discusses students who do not enter the engineering industry, academia, or who leave after a few years as 'lost' (J. Rohde et al., 2020). They argue that earning an engineering degree gives students the necessary skills and ability to have a significant positive impact on the workforce, regardless of if they enter or persist in what is typically classified as an engineering career.

In conversations about what a BME career looks like, the voices of educators and industry employers have typically been included (Ramo et al., 2019; White et al., 2020). Relatively few studies have incorporated the perceptions of students in discussions about what BME is (Ramo et al., 2019). When examining students' definitions of the field of BME, Ramo et al. argued the importance of incorporating student voices in conversations about BME to develop a "coherent field identity (Ramo et al., 2019, p. 1)". Further, student perceptions of the BME field can provide important insights on a common understanding of the possible careers in BME, which can inform recruitment and career mentoring efforts within departments.

Study Design

This study was guided by the following research questions:

What do BME students perceive as possible careers in their field? How might their views change over time?

In order to answer these questions, the careers that students perceived as possible for BME's were first identified from the data. Changes in the students' perceptions of possible BME career paths over time and observed sources of career exploration were also studied. Data used in this study were collected as part of a larger longitudinal, qualitative study focused on how upper-level BME students' experiences and professional development occur naturally, without researcher intervention, through co-curricular engagement. Qualitative research methods are commonly employed to explore participant motivations, interpretations of their experiences, and/or provide detailed descriptions of a given event or phenomena (Leydens et al., 2004; Merriam, 2009b). The first author conducted interviews with fourteen BME students at three time points spanning their third year of undergraduate study. While performing the first interviews, the interviewer observed common discussions about students' perception of possible careers in BME. In order to explore how students were discussing these ideas further, follow-up questions were added to the remaining interviews. The practice of refining research questions, data collected, and/or analysis methods throughout a qualitative research study is common. The refinement acknowledges the interconnected nature of the stages of research, where the data collection and analysis process is not linear but rather permits each step to inform both the previous and succeeding stages in the research (Case & Light, 2011). This view of research was particularly relevant for this study, which allowed for the examination of a spontaneous set of discussions observed in the interviews, but not originally in the scope of the study design.

Institutional Context. The study was conducted at a large, research-intensive, public university located in the Midwest United States. Students enrolled in the institution's BME program pursue one of three concentrations as a part of their undergraduate major: bioelectrical, biochemical, or biomechanical. Unique to the timing of this study, the university transitioned to a hybrid course format prior to the final interview, with the majority of classes offered virtually and a select few offered in an in-person format due to the COVID-19 pandemic.

Participants. Through purposeful and snowball sampling, 14 BME undergraduate students in the beginning of their third year were selected to participate in the study. The fourteen-participant sample utilized in this study is well within the range of a typical sample size for a qualitative study, as these studies rarely seek to generalize results but rather ask questions that allow for an in-depth understanding of a specific environment (Saldaña & Omasta, 2018). To protect the confidentiality of participants, direct quotes have been given a pseudonym selected by the participant followed by the interview number in which it took place. As an example, the first interview completed by Timmy (pseudonym) is referred to as TimmyI1 within the context of this study.

Interviews. Each of the participants completed a series of three 45- to 90-minute semi-structured interviews over the 1-year study period. Interviews were conducted by a BME graduate student (the first author) at the beginning of the first semester (Interview 1), near the end of the first semester (Interview 2), and towards the end of the second semester of the students' third year (Interview 3). The interviews for the third interview occurred during the early months of the COVID-19 pandemic. As a result, one participant did not complete Interview 3 and the remaining thirteen interviews were conducted virtually through video calls.

Semi-structured interviews were leveraged as a way to explore student perceptions about how their curricular and extracurricular experiences relate to their professional development as biomedical engineers. An advantage of a semi-structured interview in longitudinal studies is that while all participants are asked certain questions, allowing for comparisons across participants and time points, the interviewer also has the flexibility to add follow-up questions that allow for further exploration of participants' views on a topic if responses are interesting or unexpected (Leydens et al., 2004). Within this study, the interviewer recognized patterns in how students were describing their perceptions of the BME job market, and chose to incorporate follow up questions in the interviews that could further explore this topic (see Table A. 4 for some examples).

These discussions were extracted from the interviews for the analysis presented in this paper.

Data Analysis. A qualitative data analysis was performed to identify the careers that students perceived as possibilities within BME as well as to gather information on how they found information on possible career paths during their educational experience. Passages that mentioned career possibilities were selected from the interview transcripts and compiled into the NVivo 12 program. The first two authors identified common areas of discussion in the passages independently during the intensive reading process (Hsieh & Shannon, 2005) that followed, noting that participants named multiple possible BME careers as well as how they learned about those possibilities. For instance, the mentions of "academia", "industry", and "medical school… pre-med track" in the excerpt below were noted as possible careers in the initial reading process.

> *I think now I see that I could take my BME degree to a lot of different places, not just into academia or not just into industry, but I've heard that one third of people in BME are going into medical school or working towards, working in that pre-med track.* ***– AII1***

The first two authors then read the transcripts a second time, creating codes for possible careers (second author) and opportunities for career exploration (first author). After discrepancies and patterns between the identified career codes were discussed, the scope and meaning of codes were refined to reflect observed patterns in the career possibility discussions in the data. Conceptually similar codes were grouped into a set of categories (Academia, Industry, and Other). Interview questions that probed relative importance or interest in specific career paths were not asked; as such, the coded mentions of a career path were considered to represent a student's awareness of a career possibility. Additionally, the research questions and analytic approach presented aimed to explore what students perceived as possible rather than plausible or most interesting.

A code was counted if it was mentioned at least once by a participant. Because the intensity of the students' awareness or interest was not the focus of this study, multiple mentions of a code by a participant within a single interview were coded just once per participant. However, mentions of the same code by a participant across multiple interviews were coded multiple times (e.g., two mentions of bioinformatics in TimmyI1 would be coded once but one mention of bioinformatics in both TimmyI1 and TimmyI2 would be two codes). Definitions for how the career possibilities codes were categorized (Academia, Industry, and Other) and applied can be found in Table A. 2.

Results

The number of careers mentioned per participant suggested that students' overall knowledge of possible BME careers broadened over the course of the interview cycle, especially from Interview 1 (an average of 4.93 careers) to Interview 2 (an average of 8 careers). A closer examination of trends in the way participants discussed possible BME careers during the code application process also indicated that the number of possible careers mentioned by participants was negatively related to the students' level of certainty about their own career aspirations throughout the interviews. This level of certainty was analyzed by examining the language by which the students described their personal aspirations throughout the interviews as well as the specificity of the career paths that were mentioned. For example, students whose responses displayed confidence in their personal career aspirations in Interview 1 exhibited less growth in the number of newly mentioned possible careers between Interviews 1 and 2 when compared to students who appeared less certain about their career aspirations. Along with our analysis of what careers BME students perceived as possible upon graduation, we found that many students mentioned the positive impact of opportunities that allowed them to explore the wide array of career possibilities with a BME degree. In discussing that career exploration, participants named multiple mechanisms at the university that they found helpful in navigating their own exploration process.

BME Career Possibilities. For the analysis of BME career possibilities, the number of unique careers mentioned by each participant in Interviews 1, 2, and 3 were calculated. The total counts for the *Academia, Industry, and Other* (e.g., business, consulting, healthcare, law, public health, and more) categories are summarized in Table 17. Since Interview 3 consisted of fewer participants (n=13) than both of the previous interviews (n=14), the values in Table 17 were also normalized in order to compare across interviews. The normalized number of unique careers mentioned in each interview was calculated by dividing the total number of career codes by the number of participants. The resulting values are displayed in parentheses. A table detailing the counts for each of the individual codes (i.e., specific careers) in Interviews 1, 2, and 3 can be found in Table A. 3.

The number of careers mentioned per participant increased from Interview 1 to Interview 2. Participants mentioned an average of 4.93 different careers in Interview 1 and an average of 8 careers in Interview 2. The increase in careers mentioned between Interviews 1 and 2 came from the categories of *Industry* and *Other*. In *Academia*, the total careers mentioned by participants remained fairly constant. Comparing responses from Interview 3 to Interview 2, both the total and normalized values from Table 17 indicate that participants mentioned fewer careers in each category. Despite this decrease, the average total number of careers mentioned per participant in Interview 3 (6.54) remained higher than the average mentioned in Interview 1 (4.93).

Table 17. Total number of possible career path codes.

	Interview 1 (n=14)	**Interview 2 (n=14)**	**Interview 3 (n=13)**
Academia	11 (0.79)	11 (0.79)	10 (0.77)
Industry	28 (2)	43 (3.07)	38 (2.92)
Other	30 (2.14)	58 (4.14)	37 (2.85)
Total	**69 (4.93)**	**112 (8)**	**85 (6.54)**

The study was also interested in the total unique careers identified by students over the three interviews. Figure 5 demonstrates the growth in each participant's mentions of unique BME careers over the course of the three interviews. The number of BME careers that students communicated in Interview 1 are represented as the leftmost points on the graph. To account for repeated career codes from Interview 1, the total number of unique careers that each participant mentioned in Interview 2 was calculated by adding the number of new careers mentioned in Interview 2 to the number of careers identified by the same participant in Interview 1. Similarly, the values for the Interview 3 time point were calculated by adding the previous number of careers mentioned by the participant (i.e., the unique careers in both Interview 1 and Interview 2) to the number of new careers mentioned in Interview 3.

All participants mentioned additional unique BME careers from Interview 1 to Interview 2 (Figure 5). All but two of the students showed continued growth (mentions of additional unique careers) into Interview 3. These two students, Al and Student M, repeated the same careers in Interviews 3 that they already had mentioned in Interviews 1 and 2. However, all interviewees displayed an overall increase in reported unique career paths over the course of the three interviews. Generally, for those who showed continual growth throughout the entire interview process, the increase in the number of unique careers mentioned was larger between Interview 1 and 2 compared to the increase from Interview 2 to 3. Participants 5, 7, and 9 were the only participants who had a smaller increase in reported unique BME careers between Interviews 1 and 2 than between Interviews 2 and 3.

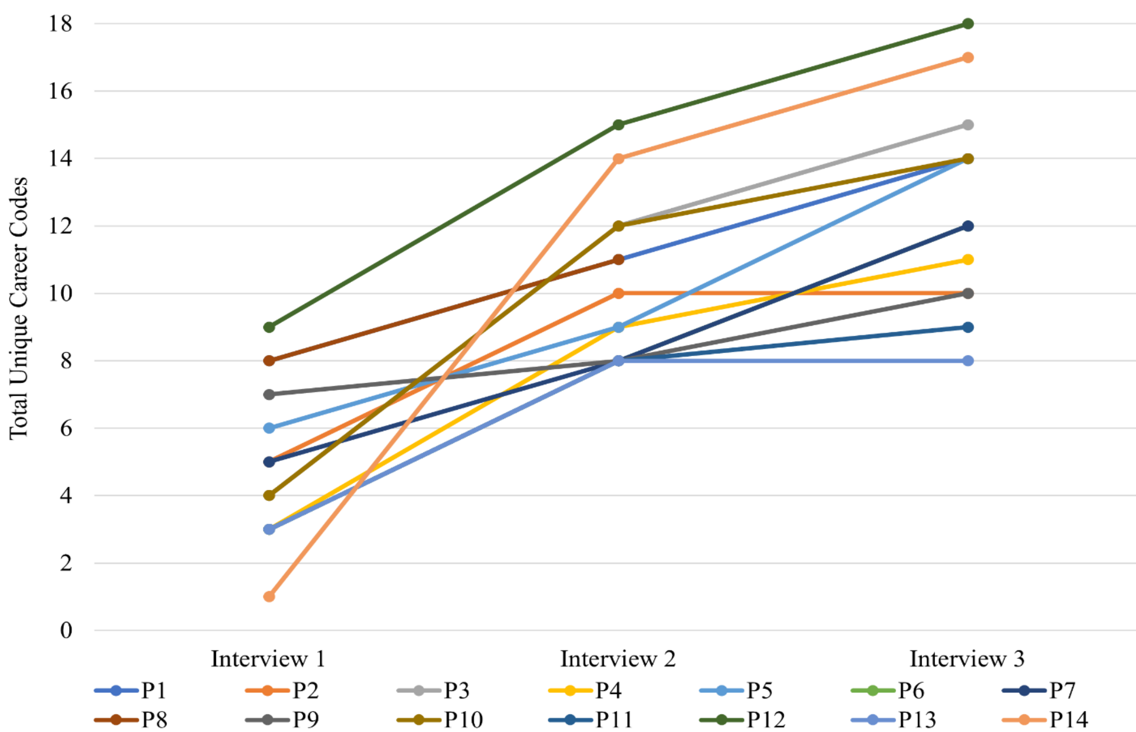

Figure 5. Total unique career codes for participants over time.

The patterns observed in Figure 5 were further explored by examining students' responses qualitatively. Table 18 shows example quotes from Participants 2 and 9 that illustrate how participants' discussions of possible careers could relate to their certainty of their own personal career aspirations at the time of the interviews. Compared to the rest of the interviewees, Al, who appeared unsure of which career they wished to pursue upon graduation based on how they described possible careers in the interviews, named a typical number of career possibilities in their first interview (5 career codes) and showed a substantial increase in the number of new careers named in Interview 2 (5 additional career codes). However, they mentioned no additional careers in Interview 3. Alternatively, Samantha who talked about personal career aspirations much more confidently in their interviews, mentioned 7 careers in their first interview but only named one (Interview 2) or two (Interview 3) new careers in the following two interviews.

Table 18. BME career paths and personal aspirations across interviews with Al and Samantha.[4]

Identifier	Example Quote
AlI1	*I think now I see that I could take my BME degree to a lot of different places, not just into academia {Academia - General) or not just into industry {Industry - General}, but I've heard that one third of people in BME are going into medical school or working towards, working in that pre-med track {Other - Healthcare}.*
AlI2	*I've been struggling with that, with what I want to do in the future. Like I thought I wanted to go into industry {Industry - General} after graduating undergrad… but like this semester, I felt like job searching for me is really stressful and very difficult… and I thought about whether I would like to stay in the industry for 30 to 40 years. And I couldn't imagine myself… in the industry for that long… I think there's so many paths that BMEs can go into. And I think that's a blessing and a curse… I think I heard that one third of BMEs are pre-med, so definitely the healthcare kinds of things {Other - Healthcare}. Like, becoming a doctor. And then, going into industry. And that could be a lot of different roles like product development {Industry - Design, Research & Development} or I know someone who's going into human factors {Industry - Human Factors, IOE}. Or quality engineering, regulatory affairs {Industry - Regulatory, Quality Engineering}. And I feel like it could also go into government jobs {Other - Patent, Law, Politics} too, like FDA or my friend is interested in pursuing a public health {Other - Public Health} degree after undergrad.*
AlI3	*Starting last semester… I began to think maybe the industry {Industry - General} isn't the best option or best choice. I couldn't see myself working in the industry for 30 to 40 years even, so I began considering other options. Right now I'm thinking about… either pursuing PA {Other - Healthcare} or the regulatory {Industry - Regulatory, Quality Engineering} side of medical devices {Industry - Medical Devices}… Yeah. I'm not too sure what I will be doing in 10 years, but right after graduation I think I would be either working in providing patient care to apply for a PA school in the future, or preparing for a grad school, or patenting {Other - Patent, Law, Politics} or regulation side of things… I think that there is a wide range of options [for BMEs], but I think it's sometimes harder for BMEs to enter into those. I feel like we have a wide option, but not everyone can have those jobs.*
SamanthaI1	*I would say that biomedical engineers can do a lot. So, so far in research, I've seen a lot of both like the wet lab side and analysis as well, even some development {Industry - Design, Research & Development} and troubleshooting {Other - Coding, Computational} and things like that… I would say that biomedical engineering gives you a wide base of knowledge, both as you get experience in the mechanical {Other - Other Engineering - Mechanical} side of engineering, but also you get experience doing electrical {Other - Other Engineering - Electrical} work and circuits. And then it also gives you an opportunity to really focus in on a specific area, which for me, I would definitely choose more of the chemical tissue engineering {Other - Other Engineering - Chemical} side.*
SamanthaI2	*Biochemical {Other - Other Engineering - Chemical}… I'm really interested in more of the research and development {Industry - Design, Research & Development} side of BME. I'm not particularly interested in medical devices {Industry - Medical Devices} or circuitry or anything like that… I think I would like to start a PhD, either immediately after [undergrad] or maybe after a gap year for my kind of*

[4] underline = prospective BME career named; {} = career code applied

	short term… but long term I'd like to be in the R&D industry… I have heard of people in BME going into things like <u>*consulting*</u> *{Other - Consulting} or there's also a lot of development and engineering positions that people go into. Development of instrumentation and more the* <u>*electrical*</u> *{Other - Other Engineering - Electrical} side. I've also heard people who take their skills from BME and just apply them to a different field in general.*
Samanthal3	*Immediately after [undergrad] I'd probably like to take a gap year working in a* <u>*research*</u> *{Academia - Research} lab of some sort, but eventually I'd like to be in grad school, probably pursuing a PhD. So that's the five year plan. I would like to be in* <u>*industry doing research*</u> *{Industry - Design, Research & Development} [in the long term]... probably for a* <u>*pharmaceutical*</u> *{Industry - Pharmaceutical} company or something like that… [BMEs can do] a lot for sure. I was actually looking at LinkedIn yesterday for work and looking at [my university] alumni in BME doing all different kinds of things, obviously from* <u>*medical devices*</u> *{Industry - Medical Devices}, … to research, to* <u>*consulting*</u> *{Other - Consulting} to all different kinds of stuff.*

Opportunities that Exposed Students to BME Careers. The qualitative examination of students' career possibilities also demonstrated the importance students place on opportunities to explore what different careers look like in BME. These discussions often occurred simultaneously with students describing realizations of what they wanted to do or how they would fit into the BME career landscape. Students described the importance of the co-curricular activities that were the focus of the original interviews, but examples of exploration opportunities also included other co-curricular settings, department level programming, and experiences in a course where professors discussed examples of BME careers. Students indicated that these opportunities gave them the ability to make professional connections, understand the types of jobs biomedical engineers have successfully obtained, get advice on how to talk about their undergraduate experiences in order to get a job in a company, and understand company cultures before entering the workforce. Students mentioned opportunities like attending programming from professional fraternities specifically for BME students, participating in BME design teams, talking with senior members of their labs (e.g., post docs and graduate students) through undergraduate research, volunteering in hospitals, attending alumni engagement socials, and hearing professors point out career paths that relate to the content taught in their courses. Further, some participants described these opportunities as ways to find out what they did not enjoy before entering the workforce. Some example quotes from interviews that demonstrate this theme are shown below in Table 19.

Table 19. Examples of where students described opportunities to explore Careers in BME.[5]

Identifier	Example Quote
MargotI2	*I think that like personal goals, from doing the research have stayed the same of just gaining new knowledge of the field of biomedical engineering, and seeing what specific types I enjoy, and seeing where I should take, further my career. Also doing research has made me possibly consider doing a PhD. So, I guess seeing what I'm interested in, like I said. Seeing if I want to go to grad school or go to a career, which I think is always, doing anything outside of class, is like always just trying to see what I like and don't like, and what I can see myself doing in the future.*
SophiaI2	*I think they [the professional fraternity] have helped me a lot with progressing through the University, or just through my career here. Then, they also helped a lot with just figuring out what you want to do in the long run [...] I feel like the network is very close-knit and very approachable. Like, when I went to career fair, and I spoke to Stryker, the representative that I talked to was the founder of my professional fraternity. It all just comes full circle. And it's just really interesting to see where people are now that have been in my shoes kind of.*
Student MI2	*I think talking to professors and their experiences are also helpful, so hearing about them I think will help structure the career path as well. And I think there are also opportunities outside the university like getting internships for experience.*
SarahI3	*There's a distinguished alumni awards lunch and one of the people who won the award she did undergrad in MechE, Masters in BME and then now she's a nurse. And so, I went to lunch, I talked to her and I was talking to another recruiter and they encouraged me to forget about an internship and just be a CNA. It was scary.*

Discussion

Upward trends in the number of possible BME careers named by students across the interviews were observed, indicating that BME students are still exploring different careers as they progress to their final year as an undergraduate. A deeper qualitative analysis of the responses indicated that students have varying levels of certainty in their own aspirations at an advanced stage in their undergraduate career. Insights from the qualitative analysis also pointed towards the importance of career exploration at multiple levels of depth. Based on the results and the literature reviewed, the authors propose implications for changes in practice and suggest research topics that warrant further investigation.

Overall, as the participants progressed through their third year, they mentioned a greater number of careers in their interviews. The expression of new, unique BME careers in these later interviews and the growth in the overall number of careers mentioned in each interview indicated the broadening of the students' understanding of possible BME careers over the course of the study. Students' changing perception of BME as field has been studied previously (Ramo et al., 2019). In their 2019 study, Ramo et al. found that students at different education levels view the field in nuanced ways, which to some degree, could link to the career exploration process studied in this

[5] *underline = exploration opportunity*

paper. Within the group of students interviewed, the correlation between the increase in the total number of codes (Table 17) between Interview 1 and Interview 2 along with the large number of new unique careers named by a majority of the students in Interview 2 (Figure 5) suggests that a great deal of career exploration occurred between the first two interviews. Moreover, the growth in the number of careers mentioned between Interviews 1 and 2 for careers in Industry and in Other fields (outside of Academia) signifies that the students' exploration of BME careers between Interview 1 and Interview 2 likely occurred in those fields and that their perception of possible careers within those areas expanded. Despite a decrease in the average number of careers named by interviewees between Interviews 2 and 3 (Table 17), continued growth in the total number of unique careers for a majority of the participants was observed (Figure 5). Additionally, nearly all of the participants mentioned new careers in Interview 3 which implies that the students continued in their exploration of possible BME careers between I2 and I3.

Interestingly, the few participants that did not show substantial increases in the number of unique careers mentioned throughout the interview process also expressed their interests and intended career aspirations clearly and confidently in the first interview. These interviewees, including Samantha, described their aspirations using language that conveyed certainty in their choices and interests (e.g., *"I'm really interested in [X]", "I'm not particularly interested in [Y]"*) and their personal aspirations remained consistent throughout the interviews. Any new career paths that were mentioned in the participants' later interviews were often discussed with reference to other individuals' pursuits and aspirations. However, the majority of participants, including Al, that demonstrated substantial increases in their total amount of unique codes during the interview process discussed their career aspirations differently. Though many of these students had also stated their intended career paths in the first interview, they were more likely to use language that conveyed doubt and uncertainty when expressing their interests (e.g., "*I'm not very sure*", "*I'm still deciding", "I think",* etc.) than the participants who did not show substantial increases (e.g., Samantha). These students used general terms when referencing possible career paths in Interview

1, often mentioning “academia” and “industry” as opposed to specific careers within those fields (e.g., “education” and “R&D”). The frequent use of these generalizations may indicate that they held limited understandings of possible BME careers at the time of the first interview. During the second interview, these participants referenced more specific BME careers and many also demonstrated an increase in their total number of unique codes, though they continued to express uncertainty about their own career aspirations. These patterns suggest that students uncertain of their career aspirations in Interview 1 had explored career options between Interview 1 and Interview 2. It seems possible that these explorations were driven by the students’ desire to achieve more certainty regarding their own career options, since these participants often emphasized their own relation to the mentioned career possibilities (“*I thought about whether I would like [X]”, “I couldn’t imagine myself [in Y]*”). By Interview 3, most of these participants appeared more certain in their professional goals, based on how they discussed career possibilities in the interview. While many participants had still not determined what career they would pursue upon graduation in Interview 3, they demonstrated a greater level of clarity regarding their BME career interests in Interview 3 than in Interview 2.

The observed trends between the number of reported career paths by participants and their level of certainty about their own career aspirations suggests that participants who have a clear understanding of their own professional aspirations likely mention fewer possible careers. Conversely, when a participant was questioning their future career aspirations, they were likely to mention a greater number of career paths, which appeared to link to their own career exploration efforts. Future research concerning students’ exploration of possible careers may wish to focus on exploring how realistic or probable BME students perceive different careers to be as well as identifying the sources from which BME undergraduates obtain new knowledge about possible career paths.

This study identified a few possible mechanisms by which participants learned about possible BME careers. Additionally, in those discussions, participants emphasized the importance of exploring career options on the development of their views of the overall BME career landscape. Exploration experiences like internships, co-ops, and research opportunities have been previously implicated as important for BME students' career choices upon graduation (Abu-Faraj, 2008; Ropella, 2003; Waples & Ropella, 2003). The results of this study indicated that smaller career exploration opportunities, like attending the alumni networking lunch mentioned by Sarah, can also have a big impact on students' career perceptions. This finding aligns with previous research from Lichtenstein and colleagues that found that students' thoughts about careers can be strongly swayed by a single experience (Lichtenstein et al., 2009). Lichtenstein's work and the current study provide strong support for the value of intentional development of career exploration opportunities for BME students, even if they are short or single time point events. Future research may wish to intentionally explore the impact that single time point career exploration opportunities have on students' career plans upon graduation to inform administrators' and educators' efforts to facilitate students' career exploration.

Limitations. The exploratory nature of this study poses some limitations on the conclusions that can be drawn from the results. First, data were collected as part of a larger study with only third-year BME students at one institution. Although qualitative research in general does not aim to be generalizable (Hesse-Biber & Leavy, 2017; Merriam, 2009b) and the recommendations made based on the results of this study focus on posing questions for future research rather than making generalizable claims, including other age groups or BME students from other institutions in the study would have added to the overall understanding of BME students' experiences with career exploration. Furthermore, the work to explore what careers were possible was also limited due to the way the data were collected and analyzed. This study focused on identifying as many careers as possible, rather than exploring to what extent participants felt the careers were realistic or interesting for them personally. Though some information about this topic was able to be drawn from the data, future work in this area could use the career codes identified in this study to develop a survey that examines students' perceptions (as realistic or interesting) on possible BME careers.

Conclusions. This study provides value to the field of BME education research by using the results of a qualitative, exploratory study on the career perceptions of a cohort of third-year BME students to inform future work. The results provide recommendations for future research that explores where students envision themselves going in a career and how educators and administrators can support students in career exploration.

CHAPTER VI

BME Professional Development Through Co-Curriculars

Abstract. *Engineering education research on student outcomes through co-curricular engagement has largely focused on connecting outcomes to experiences at a co-curricular category level. Much less work has aimed to explore what elements of those experiences could lead to student outcomes. Our research aimed to identify common elements across two co-curricular experiences that students connect to their development of professionally relevant competencies. We used a set of four longitudinal, semi-structured interviews with fourteen upper-level BME students over the course of a year to explore students' perceptions of their professional development through their co-curricular experiences. Using a qualitative causal analysis approach, we identified elements of experiences that students linked to their professional competency development through their design, research, and other co-curricular experiences like internships and professional societies. We identified "experience elements" of co-curricular experiences where through activities that we call "participant actions," students connected their experiences to the development of ten professional competency categories we identified through a literature review (business, career direction outcomes, communication, cultural, design, disciplinary, interdisciplinary, leadership, personal attribute outcomes, and teamwork). Participants connected some experience elements and participant actions to multiple competencies. The common experience elements participants identified included Independent Project Work, Project Work That Engages Multiple Disciplines, STEM Education Opportunities, and Mentorship From a Skilled Other. The common participant action identified was Reflecting on Experience. Based on our results, we provide recommendations for how educators, co-curricular mentors, and students might apply these findings in their* *contexts to support competency development. We also discuss how exploring the learning processes that lead to competence development through co-curricular engagement can benefit our understanding of engineering co-curricular learning.*

Introduction

Out-of-class, or co-curricular experiences, are important elements in engineering education because of their potential to reinforce learning and prepare students for future careers (Busby, 2015). As research on co-curricular experiences has developed, higher education institutions have placed an increased emphasis on engineering students' participation in co-curricular experiences to supplement their curricular experiences (Busby, 2015; Conger et al., 2010). While these discussions are prevalent in other engineering disciplines, these experiences play a very important role in the undergraduate experiences of biomedical engineering (BME) students. Within BME, the experiences and skills developed within the curriculum can vary substantially from program to program based on the department and faculty's research strengths (White et al., 2020). This variety in student experiences has become a hallmark of a BME student's education, but has also been linked to struggles students encounter during the transition from engineering student to engineering practitioner (Nocera et al., 2018). In some spaces, BME undergraduate students have explicitly implicated co-curriculars as a key part of preparing them for professional careers during their undergraduate experience (Berglund, 2015b; C. Jamison et al., 2020).

Drawing on the engineering education literature that demonstrates the benefits of categories of co-curricular engagement for student professional and personal development (Fisher et al., 2017; Denise R. Simmons et al., 2017), our study extends our current understanding of professional development through co-curriculars by identifying common elements of co-curricular experiences that students connect to their development of specific professional and personal competencies. Targeting an engineering student population that frequently engages in co-curricular opportunities, our study draws on BME student experiences across a range of co-curricular experiences (i.e., campus community groups, departmental clubs, project teams, internships, undergraduate research) to draw conclusions about the development of relevant professional outcome categories (i.e., business, career direction, college outcomes, communication, cultural, data, design, disciplinary, ethics, interdisciplinary, leadership, personal attribute outcomes like self-confidence and self-direction, teamwork). These categories, called competencies in this work, were inductively developed based on student outcomes discussed in relevant engineering and co-curricular literature (Fisher et al., 2017; Passow & Passow, 2017; Denise R. Simmons et al., 2017; White et al., 2020; Woodcock, 2019).

Background

Studies exploring engineering student outcomes related to co-curricular opportunities have argued that theses settings are related to the development of a variety of professional competencies (Litchfield et al., 2016). Examples include communication competence (Carter et al., 2016; Coyle et al., 2005; Dalrymple & Evangelou, 2006; Young et al., 2015), cultural competence (Oakes et al., 2018), design competence (Coyle et al., 2005; Dukart, 2017), ethical competence (Bielefeldt et al., 2016; Burt et al., 2011; Finelli et al., 2012), leadership competence (Burt et al., 2011; Knight & Novoselich, 2017; Reeve et al., 2015), and teamwork competence (Coyle et al., 2005; Young et al., 2015). Scholars have also studied connections between co-curricular engagement and students' career and personal outcomes, like self-efficacy and sense of belonging (Burt et al., 2011; Dukart, 2017; Fiorini et al., 2014; Fisher et al., 2017) as well as lifelong learning and reflective behavior (Young et al., 2015) outcomes.

Many of the engineering co-curricular studies in the literature explore outcomes in similar ways. These studies focus on exploring one or more outcomes of participation in one or more categories of co-curricular experiences (e.g., design teams, undergraduate research, affinity organizations, etc.). This approach has led to engagement recommendations that emphasize participating in a specific category of co-curricular to support the development of a given competence or student outcome. As an example, a study by Young and colleagues in (2015) looked at perceived communication, professionalism, lifelong learning, teamwork, and reflective behavior development of African American students in engineering through their co-curricular involvement. Their study examined three categories of co-curricular opportunities:

engineering clubs, underrepresented minority (URM) clubs, and ‘other’ clubs. In their analysis, they explored the connections between their categories of co-curriculars and the outcomes they measured, finding that students reported higher teamwork and reflective behavior through participation in any of the co-curriculars and that self-reported teamwork skills increased with increased engagement in engineering and other clubs. Their findings suggest the importance of the engineering and other club categories of co-curriculars for the development of teamwork skills.

Similarly, a study on multiple student outcomes related to participation in one co-curricular category, “undergraduate research” looked at development of communication, teamwork, and leadership skills (Carter et al., 2016). Their findings also focused on exploring linkages between participation in research and development of the three student outcomes, finding that students who engaged in undergraduate research reported higher skills than students who did not participate in undergraduate research, but when accounting for both curricular and classroom experiences, found few differences between students who did or did not participate. This study demonstrates the importance of considering other variables that might impact researchers’ ability to draw student outcome conclusions based solely on categories of co-curricular participation.

Extending work exploring connections between one or two co-curricular categories and a few student outcomes, some efforts in engineering education research have aimed to explore connections between multiple categories of co-curricular experiences and multiple student outcomes (Fisher et al., 2017; D.R. Simmons et al., 2017; Denise R. Simmons, Ye, et al., 2018; Denise Rutledge Simmons & Groen, 2018). For example, Fisher et al. (2017) performed a review to explore relationships between categorized co-curricular opportunities and engineering student outcomes. The work produced a framework that hypothesized connections between 20 student outcomes and 22 categories of co-curricular opportunities for engineering students. Similarly, Simmons, Creamer, and Yu also performed a review of the literature to explore the outcomes associated with out-of-class involvement, finding 10 outcome categories linked to engineering student involvement in out-of-class activities (Denise R. Simmons et al., 2017).

Simmons and colleagues (2017) have also explored linkages between out-of-class involvement and student outcomes by developing the Postsecondary Student Engagement (PosSE) Survey. This survey explores links between students' affective engagement in out-of-class activities and their perceived learning outcomes. Using PosSE, Simmons and co-authors found differences in students' choice of co-curricular involvement related to their study participants' genders and races (Denise R. Simmons, Van Mullekom, et al., 2018). Based on their results, they emphasize the importance of continued research on student co-curricular engagement, particularly in populations that are historically underrepresented in engineering and discuss the importance of a better understanding of co-curricular learning for informing how we encourage students to engage.

The engineering education studies exploring outcomes of co-curricular participation so far have contributed to our overall understanding that co-curricular engagement is important in engineering student development. However, as recognized by Faber and colleagues in their work exploring students' undergraduate research experiences, opportunities within the same co-curricular category, in their case undergraduate research, can vary by institution, major, or time of engagement (Faber et al., 2020). The variety of possible experiences present within a co-curricular category necessitates a more nuanced approach in order to extend our understanding of learning processes that connect co-curricular engagement to learning outcomes. To gain a deeper understanding of the learning processes that occur through co-curriculars, more research is needed that explores student development patterns across co-curricular categories and identifies elements of co-curricular experiences that lead to learning outcomes.

Using qualitative methods which can produce more nuanced findings in engineering education research, a study by Burt and colleagues in (2011) explored student outcomes related to engagement with co-curricular categories like internships, co-ops, service projects, and clubs or organizations. Their findings stated that students connected their general involvement in co-curricular experiences to developing leadership skills, improving their ethical decision making skills, and increasing their overall ethical development. While this study demonstrated nuances in student development of certain learning outcomes (e.g., ethics in engineering) it did not identify characteristics of the co-curricular involvement that students connected to their outcome development. Another recent study also employed qualitative methods to look at students' leadership development through involvement in competition teams (Wolfinbarger et al., 2021). Through their analysis, Wolfinbarger and colleagues identified co-curricular engagement characteristics that their participants related to leadership development through the engineering competition team experience (e.g., extent of participation, curricular exposure, precollege organizational experiences, holding leadership positions). Their study approach demonstrates an example of how researchers can develop a more in depth understanding of the learning processes involved in student professional development through co-curricular engagement. Our study similarly extends the field's current understanding of student outcome development through co-curricular engagement by employing qualitative methods to identify patterns in student's professional development and link those patterns to elements of experience that are present across categories of co-curricular experiences.

Study Design

Our work aimed to identify elements of students' co-curricular experiences that they linked to professional competency development. We used a set of four semi-structured interviews performed over the course of one year to gather data from fourteen BME students involved in co-curricular experiences at a large research university. Using prior literature to inform what competencies students may have been developing, we employed a qualitative causal approach to data analysis to identify elements across co-curricular experiences that students perceived as related to their professional competency development. Our study explored the following research question:

> *What are common elements across co-curricular experiences that students link to their development of professional competencies?*

Institutional Context. The study was approved by our institutional review board and took place within an undergraduate BME program at a large, public, research-oriented university in the Midwest United States. Around the time of the study (academic year 2019-2020), the enrollment of the BME program was approximately 400 students (~56% identified as female, ~16% had a historically marginalized racial or ethnic identity in engineering). The curricular structure of the BME program has since changed to a broader track-based system for students to pursue one of nine specializations; however, the students in this study completed degrees within the previous three-concentration program. Students selected either a bioelectrical (~11% of graduates), biochemical (~58% of graduates), or biomechanical (~31% of graduates). Recent data collected from an alumni survey indicated that approximately 26% of bachelor's degree graduates from this university enrolled in medical school, 45% went into industry or government jobs, and 29% pursued other career pathways, such as consulting and other post-secondary programs.

Participants. The first group of participants selected for this study were recruited using a criterion-based, purposeful sampling approach. Criteria for recruitment were that the student was entering their third-year at the time of the study and participated in at least one of two common co-curricular experiences (i.e., a multidisciplinary design experience (MDE) or directed research) for BME students at the study institution. Students within the research team's network who fit the criteria were emailed asking if they would like to participate in the multiple-interview study. Students in the research team's network who held leadership positions in other BME-related co-curriculars were also asked to distribute an email advertisement to their members. This approach facilitated recruitment of students in research or MDE but outside of the research team's network. After these recruitment steps were taken, the research team employed snowball sampling methodologies by asking participants to connect them with other students they felt would be interested in participating and met the selection criteria. Overall, the study recruited 14 participants, which is within the size range considered to be typical in a qualitative study (Merriam, 2009a). To protect the confidentiality of participants, demographic and participation information is provided as a summary in Table 20. Participants selected their own pseudonyms.

Table 20. Participant demographic and participation information.

Gender	Female (11)	Male (3)	
Race/Ethnicity	Asian (6)	Hispanic/Latinx (2)	White/Caucasian (6)
Co-Curricular	MDE Only (3)	Research Only (7)	Both (4)

Co-Curricular Experiences. The definition we use for co-curricular experiences in this study aligns with literature (Denise R. Simmons et al., 2017): an out of class activity that complements what students are learning in their major. In this study context, students could elect to earn course credit for their participation in some co-curriculars through mechanisms like faculty-directed research, co-op credit, or a multidisciplinary design program that provided credit to engineering design teams including but not limited to the MDE in this study. A key distinguisher for our classification of an experience as a co-curricular in this study was that students' participation in the activities did not require course credit to engage with the experience. The MDE and directed research cocurricular contexts were selected as common experiences recommended to BME students at the university where the study took place.

The focus of the MDE co-curricular was on addressing healthcare problems by supporting interdisciplinary, global health work through design and entrepreneurship strategies. At the time of the study, approximately half of the student members were BME majors, however, many other majors participated in the MDE (e.g., electrical engineering, mechanical engineering, materials science, computer science, public health, business, etc.). Multiple forms of engagement were available to students in the MDE: as a design incubator participant, on a design team, on a travel team, or as a board member.

Students at the study university were also commonly encouraged to participate in directed research, though the specific discipline of research was not specified. Several opportunities existed for students to engage in research through mechanisms like independent study credit, for hourly pay, or volunteering. Furthermore, student experiences could vary dramatically in relation to the research tasks they performed or the level of input they had in project decisions.

Data Collection. Participants were asked to participate in four interviews lasting between 45 and 90 minutes each over the course of the 2019-2020 academic year, including the summer. Participants were offered a 30 USD incentive for each interview completed. The first interview took place at the beginning of the 2019 fall semester, the second interview at the end of the 2019 fall semester, the third interview at the end of the 2020 winter semester, and the fourth interview before the start of the 2020 fall semester. Using pilot data collected from two graduate students and two undergraduate students to inform the final protocols, we developed semi-structured interview protocols that focused on students' professional development experiences through the co-curriculars selected as the focus of this study (i.e., research and MDE). Questions aimed to understand the learning processes that participants connected to their professional development. For example, one question asked students to describe a time when they experienced conflicting perspectives during a project and then asked them to describe key takeaways from that experience, including ideas they had for improving a similar situation in the future (other example interview questions can be found in Table A. 4). In addition to learning experiences in research and MDE, we also asked participants to comment on the impact of their coursework and other co-curricular involvement on their professional development. Some common experiences that were brought up included another professionally focused BME organization, co-op and internship experiences, and other volunteer or outreach work. Each participant interview was recorded and then transcribed verbatim using a transcription service.

Data Analysis. We analyzed interview transcripts in a two-phase coding process. In the first phase of coding, the first author read through each transcript, deductively coding segments of interviews (Hsieh & Shannon, 2005) that linked to competencies previously described as important in engineering education literature. The competency coding scheme used was developed by synthesizing literature that defined professionally relevant student outcomes from three areas: engineering education broadly (Passow & Passow, 2017), biomedical and interdisciplinary engineering (White et al., 2020; Woodcock, 2019), and co-curricular engagement in engineering (Fisher et al., 2017; Denise R. Simmons et al., 2017). We used the term competencies to describe the broad range of professionally relevant student outcomes discussed in the literature. The term ‘competencies’ was used to capture students’ possession of relevant knowledge (e.g., conceptual disciplinary knowledge), personality traits (e.g., self-confidence), or skills (e.g., teamworking, communication) for the professional working world. The categories of competence described in those five studies were synthesized to represent the thirteen competence codes we used in this study (see Table 21).

Table 21. Competence coding scheme synthesized from relevant literature.

Competence	Codes from Literature
Business Competence	Make Decisions, Devise Process (Passow & Passow, 2017); Critical Thinking, Strategy (Fisher et al., 2017)
Career Direction	Career and Professional Development (Denise R. Simmons et al., 2017); Networking (Fisher et al., 2017)
College Outcomes	Satisfaction with College, College Belongingness and Connectedness (Denise R. Simmons et al., 2017)
Communication Competence	Communicate Effectively (Passow & Passow, 2017); Communication Skills, Academic And Social Engagement (Denise R. Simmons et al., 2017); Interpersonal Communication, Written Communication (Fisher et al., 2017; White et al., 2020); Public Speaking (Fisher et al., 2017); Technical Presentation (White et al., 2020); Communications Skills Across Domains (Woodcock, 2019)
Cultural Competence	Cross-cultural Skills, Global Awareness (Fisher et al., 2017); Intercultural Competence (Denise R. Simmons et al., 2017); Knowledge Of Non-disciplinary Perspectives (Woodcock, 2019)
Data Competence	Interpret Data, Measure Accurately (Passow & Passow, 2017); Statistics, Signal Processing, Instrumentation (White et al., 2020)
Design Competence	Gather Information, Define Constraints, Think Creatively, Design Solutions (Passow & Passow, 2017) Solve Problems (Fisher et al., 2017; Passow & Passow, 2017; White et al., 2020); Design Experience (White et al., 2020); Creativity (Fisher et al., 2017)
Disciplinary Competence	Experience With Relevant Software, Regulatory Procedures, Biomaterials, Quantitative Biology, Biomechanics, Advanced Courses in Traditional Engineering, Advanced Courses in Traditional Engineering, Programming Skills (White et al., 2020); Apply Skills, Apply Knowledge (Passow & Passow, 2017); Disciplinary Knowledge (Fisher et al., 2017); Intellectual Development (Denise R. Simmons et al., 2017); Knowledge of Disciplinary Perspectives (Woodcock, 2019)
Ethical Competence	Civic Responsibility, Ethics, Humanitarianism (Fisher et al., 2017); Take Responsibility (Passow & Passow, 2017)
Interdisciplinary Competence	Integration of Knowledge Domains, Reflective Behavior, Critical Awareness (Woodcock, 2019)

Leadership Competence	Coordinate Efforts (Passow & Passow, 2017); Leadership Development (Denise R. Simmons et al., 2017); Organizational Management (Fisher et al., 2017)
Personal Attribute Outcomes	Self-confidence, Self-direction, Time Management, (Fisher et al., 2017); Take Initiative, Expand Skills (Passow & Passow, 2017); Persistence, Personal and Social Development (Denise R. Simmons et al., 2017)
Teamwork Competence	Teamwork (Fisher et al., 2017); Team Projects (White et al., 2020)

Causal Analysis. After the transcripts were deductively coded for competencies, the first author looked at passages coded for a given competency in each of the participants interviews, memoing about the level of development for each competency and tagging passages that demonstrated possible explanations of how the competency was developed. In particular, we were interested in exploring how students connected experiences within a co-curricular to the development of a competency. This goal aligns with the use of causation coding in qualitative research (Maxwell, 2004; Miles et al., 2018; Saldana, 2016b), which has been described as being a useful "heuristic for considering or hypothesizing about plausible causes of particular outcomes" p. 189 (Saldana, 2016b). Qualitative education research scholars have noted that this approach is particularly beneficial for researchers aiming to explore causal processes more directly, rather than depending on correlational data provided by quantitative approaches to causal inquiry (Maxwell, 2004).

To establish causal explanation, we used an approach described by Saldana (2016), where the researcher uses participant data to identify antecedent condition(s) (i.e., the baseline conditions within in a study), mediating variable(s) (the events, states, processes, or factors that initiate change), and outcome(s) (the result of the antecedent condition and mediating variable) (Miles et al., 2018). In this study, we focused on identifying outcomes that were the competency categories from our coding scheme, and then aimed to identify *experience elements* and *participant actions* that students linked to that competency outcome. We also worked to identify *experience elements* and *participant actions* that were present across multiple co-curricular categories. Following Saldana's (2016) process, we explored patterns of repeating antecedent conditions and mediating variables, looking for opportunities to establish cross-case causal relationships between *experience elements* (i.e., antecedent conditions), *participant actions* (i.e., mediating variables) and competency outcomes. The overarching goal of this approach was to determine possible elements of a co-curricular experience that could lead to competency development, but as designed, this study cannot claim to capture every *experience element* that could play a role in the development of a given competency.

When discussing the usefulness of causation coding in qualitative research, Maxwell (2004) also noted the importance of study design in increasing the trustworthiness of causal interpretations (Maxwell, 2004). Our study employed comparison strategies (across time, individuals, and co-curricular settings) to look for cases where an outcome was not present in the absence of a presumed *experience element*, strengthening our confidence in the *experience elements* identified. Similarly, the intensive, long term engagement with participants in this study helped us rule out spurious associations based on one or two instances of a relationship. Maxwell also described long-term involvement as helpful for collecting rich data stating that a rich data set helps support the advancement of a fuller picture of the development process.

Limitations. This study was limited by our intentional scoping of students in one discipline at one institution. While the decision ensured some continuity across curricular experiences and helped us make comparisons across co-curricular and student outcome contexts, the disciplinary focus could impact the presence of specific competency outcomes in our data based on how these students differently prioritize their development and engagement compared to another discipline or institution. Finally, the broad scope of the competencies we aimed to explore in our interviews limited the relative depth of discussion participants had on any given competency. This scope may have affected our ability to identify additional or more nuanced *experience elements*. Given the results of this approach for identifying elements of experience, we believe future work using in-depth interviews and qualitative causal analysis is a promising approach to deeply explore elements of co-curricular experiences that can lead to student competency outcomes.

Results

We identified 17 unique *experience elements* and 18 unique *participant actions* (see Table 22 for a full list of the codes generated) that our participants linked to competency development. We were able to identify *experience elements* for many of the competencies in our competence coding scheme. However, there was not substantial enough data to identify *experience elements* that could lead to College Outcomes, Data Competence, or Ethical Competence. In Table 22, we give brief descriptions of each *experience element* and *participant action* pairing that students attributed to the development of a competence in our coding scheme.

In some cases, we connected multiple *participant actions* to one *experience element* (i.e., Independent Project Work, Mentorship From a Skilled Other, and STEM Education Opportunities) which then led to different competencies based on the *participant action* associated with it. For example, participants connected Independent Project Work to Business, Design, and Leadership Competence through different *participant actions* performed during their engagement. Similarly, students in this study linked the *participant action* Reflecting on Experience to multiple competence outcomes (i.e., Career Direction and Cultural Competence). Table 23 demonstrates relationships between *competence outcomes, participant actions*, and repetitive *experience elements* and *participant actions* in our data.

In the following subsections, starting with the *experience element* Independent Project Work, we present four key *experience elements* (i.e., Independent Project Work, Project Work That Engages Multiple Disciplines, Mentorship From a Skilled Other, and STEM Education Opportunities) and one *participant action* (i.e., Reflecting on Experience) that led to a variety of competence outcomes in our data. Finding that in some cases, the *experience element* Mentorship From a Skilled Other can lead to the *participant action* Participating in Broader Organization Functions and then to the *participant action* Presenting Disciplinary Material, we discuss a relationship in our data between two *participant actions* that can lead to Communication and/or Disciplinary Competence (see Figure 6)

Table 22. Full list of experience elements and participant actions organized by competence outcome.

	EXPERIENCE ELEMENT	PARTICPANT ACTIONS
Business Competence	Independent Project	Performing Business Analysis
	Participants performed cost analysis activities such as making decisions about cost versus quality tradeoffs in in research and internship opportunities.	
Career Direction	Mentorship from Skilled Other	Soliciting or Receiving Career Goal Advice
	Participants most commonly described development through opportunities in research to receive career advice from their mentors, and also gain access to other BME professionals who could give advice.	
	Participation in Multiple Similar Projects	Reflecting on Experience
	Participants who used reflection on multiple experiences to inform their career direction sometimes compared experiences in the same type of co-curricular, while others made connections between different types of co-curriculars, or even between co-curricular and curricular experiences.	
Communication Competence	Regular Organization Meetings	Establishing an Agreed Upon Organizational Structure
	Participants described establishing an organizational structure (e.g., meeting minute notes, expectations for starting each day in the lab) as a group (e.g., in research projects, internships, and MDE teams) that built communication competence through the activity and supported communication throughout the collaboration.	
	Mentorship from Skilled Other	Participating in Broader Organization Functions
	Participants described development through opportunities in research, design project work, the MDE in this study, and internships to perform activities like observing communication norms in realistic settings or presenting their progress to a larger part of the organization.	
	Networking Opportunities	Practicing Elevator Talks + Reflecting / Receiving Feedback
	Participants credited networking activities (e.g., in internships, at career fairs) where they could give elevator pitches or brief summaries of their work and receive feedback to building communication competence.	
	Academic Participation	Publishing and/or Presenting
	Participants discussed their prioritization on performing activities in academic spaces (e.g., conferences, symposia, etc.) that allowed them to publish or present.	
Cultural Competence	Collaboration with Culturally Focused Discipline	Reflecting on Experience
	Participants described opportunities to collaborate with a culturally focused discipline through multiple co-curricular opportunities (e.g., MDE, research outside of engineering).	
	Experience with 'Other' Culture	Reflecting on Experience
	Participants described opportunities to experience another culture through multiple co-curricular opportunities (e.g., MDE, instructional aide positions, and design challenges).	
	Formal Training through University	Reflecting on Experience
	Participants described opportunities to connect their co-curricular experiences (e.g., MDE) to cultural competence development through their elective engagement with formal training available at the university (e.g., design centers, minors coursework).	
Design Compete nce	Independent Project	Making Design Decisions
	Participants discussed multiple forms of independent projects (i.e., in research, internships, design challenges) that gave them the autonomy to make design decisions.	
	Early-Stage Project Work	Participating in Project Set-up

	Participants discussed the opportunity to participate in the setup of the projects' goals and constraints for their design competence development.	
Disciplinary Competence	Disciplinary Contextualization	Connecting Course Material to Project Work or Vice Versa
	Participants credited opportunities to connect concepts and skills back and forth between their co-curricular (e.g., MDE, research, and internship experiences) and curricular experiences for solidifying conceptual understanding.	
	Participating in Broader Organization Functions	Presenting Disciplinary Material
	Participants described development through opportunities in research and internships to present disciplinary material that supported their understanding of concepts.	
	STEM Education Opportunities	Teaching Peers Disciplinary Concepts
	Participants engaged in STEM education positions across a spectra of levels (e.g., grader, or course material design), and emphasized its utility for reinforcing disciplinary concepts.	
Interdisciplinary Competence	Project Work That Engages Multiple Disciplines	Explaining and Learning Material with Others
	Participants discussed multiple co-curricular opportunities (e.g., in research, internship, and MDE projects) to explain and learn material from people in other disciplines.	
	Project Work That Engages Multiple Disciplines	Recognizing Tradeoffs of Disciplinary Approaches
	Participants in multidisciplinary MDE, internship, and research projects had opportunities to hear disciplinary tradeoffs presented and consider disciplinary tradeoffs in their decisions.	
Leadership Competence	Independent Project	Engaging Multiple Stakeholders in Implementation
	Participants described a variety of project opportunities (e.g., in MDE, MDE travel teams, and internships) that necessitated engaging multiple stakeholders to implement.	
	Peer Team Participation	Practicing, Failing, Reflecting on Leadership
	Participants talked about how peer team settings (e.g., in MDE or other university sponsored design challenges) gave them opportunities to practice, fail, and adjust their leadership approaches.	
	STEM Education Opportunities	Teaching Mentees Disciplinary Concepts
	Participants engaged in STEM education positions across a spectra of levels (e.g., k-12 outreach or tutoring, BME instructional aide), and acted in a leadership position throughout that task.	
Personal Attribute Outcomes	Repetition or Exposure to Disciplinary Practices	Applying through Experience
	Participants discussed self-confidence development over time through repetition and exposure to disciplinary practice in spaces like internships and research opportunities.	
Teamwork Competence	Team Hierarchy or Roles	Establishing a Shared Understanding of the Project
	Participants discussed the value of having a team hierarchy or stated roles (e.g., in MDE, internships, and research) for establishing a shared understanding of a project's goals and milestones.	

Experience Element: Independent Project Work. Participants connected Independent Project Work within their co-curricular experiences to three competency outcomes: Business Competence, Design Competence, and Leadership Competence. Independent Project Work was defined as an opportunity to perform project work individually or have independence to make project decisions. We saw evidence of

Business Competence development through Independent Project Work when students participated in cost analysis activities such as making decisions about cost versus quality tradeoffs. For example, Detroit, an MDE participant, described an opportunity during his summer internship (see Table 23 for quote). Participants also described multiple forms of independent projects (i.e., in research, internships, design challenges) that gave them Design Competence exposure, each of which gave them the autonomy to make design decisions. For example, Sparks, a research participant, discussed designing a portion of her research mentor's project. Beyond cost considerations, she also needed to account for timing aspects of the experiment she would be designing when setting up the project (see Table 23 for quote). In contrast, Bianca did not discuss developing Design Competence in her research experience and instead discussed a desire to develop her own project after completing a project heavily guided by her research mentor:

> *I think just being able to do more things by myself. I kind of was doing the same things every ... We were running similar experiments every time, so I could do all of those by myself and I was the one who was setting it up and running it and stuff, but just maybe doing a whole project alone. Now that he's graduating, I have more room to work under someone else and learn about different things in the same lab. I can shift people and learn different things. But also, I could also do my own project.* ***– Bianca, I3***

Participants also linked Independent Project Work to their Leadership Competence development when their project (i.e., in MDE, MDE travel teams, and internships) necessitated engaging multiple stakeholders to implement. Student M discussed their experience with navigating the responsibilities of her leadership position when coordinating a service trip through her MDE in Interview 2 (see Table 23 for quote).

Experience Element: Project Work That Engages Multiple Disciplines. Participants similarly discussed an *experience element* where they performed project work that engaged multiple disciplines. Through Project Work That Engages Multiple Disciplines, participants described two *participant actions*, each of which they linked to their development of Interdisciplinary Competence. Participants described gaining Interdisciplinary Competence through opportunities to explain and learn material from people in other disciplines (e.g., in research, internship, and MDE projects). They also discussed how their ability to hear or recognize disciplinary tradeoffs in project discussions linked to Interdisciplinary Competence. In MDE projects like described by Sophia in Table 23, participants had opportunities to explain and learn technical material with their engineering peers outside of BME. In research projects where multiple disciplinary perspectives were present like the one Honey describes during an interdisciplinary research meeting (see Table 23 for Description), participants had the opportunity to hear and consider the disciplinary tradeoffs associated with performing project work.

Experience Element: STEM Education Opportunities. Another *experience element* participants frequently discussed was Science, Technology, Engineering, Mathematics (STEM) Education Opportunities. In these opportunities, students engaged with educational tasks in a STEM context (e.g., course content creation, tutoring, instructional assistant positions). The STEM Education Opportunities were not part of the MDE or research experiences that study recruitment was based on. Instead, participants discussed other co-curricular engagements that facilitated participation in STEM education positions across a spectra of levels (e.g., k-12 outreach or tutoring, BME instructional aide, grader, or course material design). Participants described these teaching experiences in line with development of Disciplinary Competence as well as Leadership Competence. For example, Al, an MDE participant, talked about re-learning course concepts through an opportunity to develop course material for a BME course over the summer (see Table 23 for quote), while Bianca talked more about her STEM Education Opportunity in Interview 4 as developing Leadership Competence (see Table 23 for quote).

Table 23. Examples of common experience elements linked through participant actions to competence outcomes. Text in quotes that we have altered for clarity or to protect participants' confidentiality is indicated in brackets (e.g., [Midwest University] as a replacement for the name of the study institution.

EXPERIENCE ELEMENT	PARTICPANT ACTION	COMPETENCY OUTCOME	PARTICIPANT QUOTE
Independent Project Work *Students have an opportunity*	Engaging Multiple Stakeholders in Implementation	Leadership Competence	Participant: *Last year, all of us were engineers, but this year, [some members are] not engineers, [so] they're more interested in learning about the social issues in [Partner Community] and learning about the health inequities. [But] because the more engineering and science majors, they're looking for more*

to perform project work individually or have independence to make project decisions.			*professional development experiences there, it's hard to find the right balance between the different activities.* Interviewer: What has been your approach to finding that balance so far? Participant: *At our meetings I'm trying to get everyone to talk about what they're looking for through this program and also communicating with our community partner there to see how much of each activity that they could organize for us. And then laying out expectations so that we're all happy with having both engineering, biotech companies, and the service experience.* ***– Student M, I2***
	Making Design Decisions	Design Competence	*I think that it was cool to learn how you design an experiment like that and design a panel, and just thinking about, like in the real world... In a school lab you don't have to think about, "Oh, I need to buy my supplies", but when you're designing your own experiment in a lab it's your responsibility to buy your supplies and go on to whatever website and get whatever you need and know when you want to pay more for something and when you don't want to pay more for something. So it was interesting to look into that and think about your whole timeline of things because now experiments span over weeks and you have to think about when you're free in the next four weeks to do something because the [experiments] need a certain number of days.* ***– Sparks, I2***
	Performing Business Analysis	Business Competence	*So, I presented the different options I deemed were the most efficient to the engineering support teams. And then I was able to show them what my process was. It was seeing like, okay, why X product was the best for our scenario as opposed to the current models or just slightly improving on our models […] in terms of the business aspect, I did an economic kind of research of that and seeing how much this pump would cost. The overhead cost compared to the current models, seeing how, I guess how much money would be saved due to the inefficiency increases. And showing them, if we change this, we would have to spend X amount more at the beginning, but over time we could save like $1000 per year, just based on electrical costs without even taking into consideration the cost of maintenance and downtime.* ***– Detroit, I4***
Project Work That Engages Multiple Disciplines *Students have an opportunity to collaborate with individuals from different disciplines on a project.*	Explaining and Learning Material with Others	Interdisciplinary Competence	*Yeah, being able to... because we can learn a concept that mechanical engineers learn, and we can solve this with the CAD. You can learn how to make the same part a completely different way and not understand what it is that the other person did, or not be able to work off of someone else's work. I think being able to even just try to understand. Like, in that example, the CAD, one of the students in BME who had taken, I think it was in 350 that he had learned how to make something. The mechanical engineer just had no idea how to even just edit the part that he had made. They needed to talk through what they did in order for one to understand the other, and then for the part to, I don't know, change whatever it needed change.* ***– Sophia, I2***
	Recognizing Tradeoffs of Disciplinary Approaches	Interdisciplinary Competence	*It was cool to be able to understand how they were able to communicate with each other without making their perspective feel more important than another perspective. They would still acknowledge like, "Oh, yes, it's really important to be able to get this funded, and I understand that if we do things this way, people will like it less. Therefore, it would get funded less. However, I*

			think it's a risk that is worth taking because," and they'd talk about their perspective, whether that was a BME or a biology-focused perspective or a clinician perspective. It was really cool to be able to see that because they're all genuinely working together. ***– Honey, I3***
STEM Education Opportunities *Students have an opportunity to engage with educational tasks in a STEM context (e.g., course content creation, tutoring, instructional assistant positions).*	Teaching Peers Disciplinary Concepts	Disciplinary Competence	*When I was learning like BME [course] material, the material was completely new for me. I remember. So it was kind of hard understanding the concepts and even for like the lab too, it used to be BME [course] lab, where like all the labs were together and now they split it into three parts. And even as I was doing the [course] labs, I was always confused about like the [specific content] lab parts, but I think actually working on the material and like looking at the lab manuals over and over again helped me kind of understand the concept a little bit more than before.* ***– Al, I4***
	Teaching Mentees Disciplinary Concepts	Leadership Competence	*I always want to do things like that, like TAing and mentoring and things like that to give back. Because I participated in a lot of those programs when I was in high school, and also undergrad, underclassmen sort of thing. But I feel like I never really have the time, because in the summer you want to do internships, or REUs and things like that. So this was, I finally had time, […] I think they emailed about it or something, and they're like, "We're looking for TAs and RAs." It seemed like a good fit. I just wanted to be able to do something. I always like doing STEM-promoting things, because I feel like that was something I did a lot in high school. I went to STEM programs […] so I was just like, "Oh okay, I'll apply," and then I interviewed. […] We were teaching high school kids, and we were using some website that wasn't MATLAB or anything, so it was pretty intuitive.* ***– Bianca, I4***
Mentorship from Skilled Other *Students receive mentorship from an individual with a higher professional or educational standing.*	Participating in Broader Organization Functions	Communication Competence	*And even though, I guess, some PIs don't care if you go to the lab meetings, it was really good for me to go and hear, like, "This is what everybody else is working on, and these are the things that are available." And see how other people interact with the PI, and each other, and just what is normal in general and what's really out there.* ***– Sarah, I1*** *I think sometimes [Taylor] and [Benji] have different ideas of how to represent something, but it's never in a negative way. They're like, "Just talk it through," and then one of them is like, "Oh yeah, that's actually the better idea." I do a lot of listening. It's good to hear people talk about things, even if they're above your head, but half the stuff I'm telling you right now, I would have no idea what I'm talking about two months ago.* ***– Sparks, I1***
	Soliciting or Receiving Career Goal Advice	Career Direction Outcomes	*Starting research, and talking to grad students was probably the thing that helped me. And being able to have those conversations young, as a freshman, as a sophomore, and them telling me like, "Oh, you should do an REU, you should do a summer research thing here." Just sort of guiding me down the path. I guess I decided pretty early, so that pushed me towards that path very quickly.* ***– Bianca, I4***

Experience Element: Mentorship from Skilled Other. Our participants also discussed the potential impact of the *experience element* Mentorship From a Skilled Other. In this *experience element*, we used 'skilled other' to distinguish these mentorship experiences from peer-to-peer mentorship experiences, defining the *experience element* as mentorship from an individual with a higher professional or educational standing. Participants linked Mentorship From a Skilled Other with Communication Competence and Career Direction development. These experiences most commonly occurred in research settings, but they also happened in spaces like coursework outside of BME requirements, design project work, the MDE in this study, and internships. Participants described Career Direction development through opportunities to receive career advice from their mentors themselves, and also gain access to other BME professionals who could give advice like Bianca described in Interview 4 (see Table 23 for quote). When Mentorship From a Skilled Other facilitated the *participant action* Participating in Broader Organization Functions (e.g., full team meetings, socials, etc.), participants also described the development of Communication Competence. Their participation ranged from observation of communication norms in realistic settings to presenting their progress to a larger part of the organization. For example, Sarah and Sparks, both research participants, discussed the value of observing lab meeting conversations for establishing their own understanding of communication norms (e.g., what topics are normal, what terminology to use, etc.) in those settings (see Table 23 for quotes).

Participant Action: Reflecting on Experience. We also identified one *participant action,* Reflecting on Experience, that participants connected to multiple *competence outcomes.* Reflecting on Experience was defined as a student's effort to make sense of their experiences and synthesize their learning outside of the reflecting we asked them to perform as part of the interview process. In our data, participants most often linked Reflecting on Experience to Cultural Competence development, but they also discussed how it helped inform their Career Directions. Participants who used reflection on multiple experiences to inform their career direction sometimes compared experiences in the same type of co-curricular (e.g., one research lab to the next), while others made connections between different types of co-curriculars (e.g., MDE and an internship or research and an internship), or even between co-curricular and curricular experiences (e.g., MDE and the content in a course). In Interview 4, Samantha discussed her process for considering future careers by considering what she had learned in all of the research projects and computer science minor coursework she had participated in.

> *I definitely think just being involved in BME and seeing all the different types of research that are happening here has been really important [for deciding what I want to do for a career]. I mean, working in a couple of different research labs on campus and then taking computer science classes and thinking about how I could apply those skills.*
> ***– Samantha, I4***

When participants described their Reflecting on Experience leading to Cultural Competence, it was done in connection to experiences with the following *experience elements*: Collaboration with Culturally Focused Discipline (e.g., Bianca discussing social science research in Interview 1), Experience with ‘Other’ Culture (e.g., Sophia discussing a teaching experience in interview four), Formal Training through University (e.g., AJ discussing how a class for their minor connected to their MDE experience in Interview 1). In each case, participants linked multiple experiences, sometimes including curricular experiences, to make sense of the Cultural Competence they were developing.

> *We were starting a new project so I got to help make all of the tasks. All of the questions that we ask the kids […] All of the people who spoke [different language], they would run things by us. […] So it was a lot of going back and forth. "Okay. In our culture we say this and is that confusing?" Just certain slang, seeing other people from different backgrounds and doing that stuff was cool. But they [the social sciences lab] do think differently, I think. It's a different environment for sure and it's less about data and more about qualitative stuff. […] It's more like, "Okay. How does social factors affect this?" And we do interviews and we look at things like where they grew up, how long have they been in the U.S.? All these things that you don't really have to consider when you're working with cells and stuff. It's kind of humanizing the research experience, which is cool. And I feel like it's cool to just sit there and they're talking about the root of this word is going to confuse the kids or how do people think? That stuff you don't really think about. So it's cool that they're always thinking in that way. I feel like they just view people differently because they look at everything instead of just being logical or the numbers, what you see is what you get, yeah, the data I guess, you know?* ***– Bianca, I1***

> *I think that also being a [teaching assistant] for [engineering intro course], and I think, in that role, it kind of is […] Like I'm getting different experiences from that, like completely different experiences, but I think in the end, through that, I realizing how passionate I am about just equity, in terms of education, but then*

> *also in terms of healthcare. And in terms of just accessibility to a bunch of different things. And, in that, I'm realizing just how different and how different experiences can really shape, not just who you are, but also what you want to do and who you want to be.* ***– Sophia, I4***

> *I took a […] class […] and I really, really enjoyed that class, especially because it talked a lot about how different areas of the world and different cultures have different ideas when it comes to health, and one might be more preventative while one is more treatment-based, and one might have more religious aspect to it while one is more like science and just basic facts, and what you get on diagnostics and stuff. So I thought that was really interesting to learn about and then be able to think about for, in terms of our [MDE] project in [Partner Community], because being able to incorporate culture into how our product would be used or how it would be accepted into the daily life or if it was considered intrusive to the patient or anything in terms of what [Partner Community] is used to based on proximity and comfortability with the medical devices.* ***– AJ, I1***

Nuanced Relationships Between Experience Elements, Participant Actions, and Competency Outcomes. Our analysis also found evidence of a relationship between the *experience element* Mentorship form a Skilled Other and two *participant actions,* Participating in Broader Organization Functions and Presenting Disciplinary Material. When participants experienced the *participant action* Participating in Broader Organization Functions alone, they discussed developing Communication Competence. However, if their Participating in Broader Organization Functions led to Presenting Disciplinary Material through that participation, they also discussed the development of Disciplinary Competence. Figure 6 demonstrates this relationship and Honey discussed experiencing it through her research engagement in Interview 1 below:

> *He'd [the lab PI] also have the undergrads sign up for slots. […] The undergrads would present about either a topic that they've picked, or the research that they've done so far. And so my last lab presentation was about PCR because everyone just mutually decided that they didn't know enough about PCR and how the math worked with PCR. I did most of the PCR in that lab, so I was supposed to explain that to the grad students, and I did it.* ***– Honey, I1***

Discussion

In this study, we used student interviews to identify elements of co-curricular experiences and *participant actions* that could lead to professional competency outcomes. By looking for patterns across data from multiple co-curriculars, we identified transferrable *experience elements* that could serve as opportunities to develop a variety of professional competencies for engineering students. Participants connected *experience elements* to multiple competencies from our competency coding scheme (i.e., Business Competence, Career Direction Outcomes, Communication Competence, Design Competence, Disciplinary Competence, Interdisciplinary Competence, and Leadership Competence). In this section, we discuss our findings relevant to the engineering co-curricular research that motivated the study, learning theories that could connect to the relationships we found in our data, and then discuss how our work can inform research on professional competency development in future studies. Finally, we discuss what our findings could mean for 1) educators designing courses and 2) mentors supervising co-curriculars. In a related section, we provide considerations for students choosing co-curriculars to engage with based on our findings.

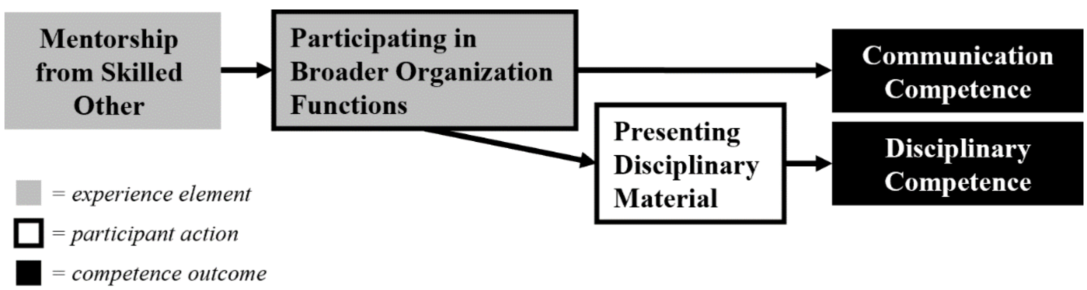

Figure 6. Demonstrated relationship starting with Mentorship From A Skilled Other leading to participating in broader organization functions and in some cases presenting disciplinary material in relation to the development of communication and disciplinary competence.

Connecting Findings to Prior Engineering Co-Curricular Research. Coming back to the two co-curricular contexts we used to as inclusion criteria for this study, we can draw comparisons between our work and previous research on professional learning outcomes associated with co-curricular participation in engineering. For example, a number of previous studies have explored the professional outcomes of students participating in an undergraduate research co-curricular contexts (Carter et al., 2016; Dalrymple & Evangelou, 2006; Faber et al., 2020). However, while looking for patterns in communication, leadership, and teamwork development, Carter and colleagues (2016) found limited differences in research participants versus non-participants after controlling for curricular and classroom differences. In Faber and coauthors work, they highlight the difficulties associated with categorizing undergraduate research broadly because of the variety of experiences that could fall under this category of co-curricular experience. Our findings suggest *experience elements* within an undergraduate research experience that can lead to competency outcomes like the teamwork (e.g., through team hierarchies or roles), and communication (e.g., Regular Organization Meetings, Mentorship From a Skilled Other, and Academic Participation) outcomes studied by Carter et al. (2016). Furthermore, these *experience elements* were often also present in other co-curricular categories of experience (e.g., MDE, internships), indicating the potential for an approach to engineering co-curricular research that can begin to understand the learning processes that occur in multiple co-curricular spaces in addition to identifying potential professional outcomes.

We found similar connections between the outcomes researchers have connected to co-curricular design projects and other engineering club experiences and those our participants connected to their MDE co-curricular. For example, in the study by Young and colleagues (2015), participation in an engineering club was associated with higher teamwork skills. In Fisher et al.'s (2017) study, project teams were associated with outcomes in our Business Competence, Career Direction Outcomes, Communication Competence, Design Competence, Disciplinary Competence, Ethical Competence, Personal Attribute Outcomes, and Teamwork Competence categories. Drawing on the evidence in our data, participants have also developed Cultural Competence and Interdisciplinary Competence through engineering project teams that have *experience elements* like Collaboration with Culturally Focused Discipline, Experience with 'Other' Culture, or Project Work That Engages Multiple Disciplines. The MDE in this study was interdisciplinary and globally oriented, two characteristics that made it unique from other project teams at the university where this study took place, and may connect to the presence of the *experience elements* our participants connected to the Cultural and Interdisciplinary Competence development.

Connecting Findings to Learning Theories. We also found that some of the patterns leading to professional competency development in our data could be linked to both cognitive and social learning theories, pointing to the importance of leveraging multiple theories to understand students' learning in these settings. In particular, we saw links to both experiential learning as described by Kolb (2015) and situated learning in landscapes of practice as described by Wenger-Trayner (2015).

Kolb describes experiential learning cognitively using a four phase cycle of experience, reflection, conceptualization, and application. In this cycle, a learner has a new learning experience and then reflects on how the experience went. Then the learner moves into the conceptualization stage where they incorporate what they learned from the new experience into how they already understand the problem-space and can then apply that knowledge to a new scenario and start the cycle again. In this study, the importance of reflection for competence development appeared multiple times. We saw connections to participants' career direction outcomes, communication competence development and cultural competence development through forms of reflection. If participants did not reflect while engaged in the experience elements linked to these outcomes, we did not see connections between the *experience element* and the *competence outcome*. This finding points to the importance of a student's active cognitive engagement while participating in an experience and may provide insights into strategies educators can use to improve the learning experience of students in curricular settings.

Using Wenger-Trayner's situated learning theory, we also saw evidence of social learning in the data analysis we performed. In particular, *experience elements* demonstrating opportunities to experience legitimate peripheral participation in a specific BME community of practice as well as develop knowledgeability to navigate across multiple communities of practice present in the BME professional landscape. Students experienced legitimate peripheral participation through Independent Project Work and Mentorship From a Skilled Other *experience elements* that allowed them genuine, scaffolded participation in a professional setting. Furthermore, their engagement with Multiple Similar Projects and Projects that Engaged Multiple Disciplines may have helped them develop what Wenger-Trayner calls knowledgeability, or the skills to navigate across multiple communities of practice and make connections between them. Students' connection of these *experience elements* to

Career Direction Outcomes and Interdisciplinary Competence development further supports the idea that they may be developing knowledgeability within the BME professional practice landscape. By examining the learning processes occurring within and across co-curricular contexts, we were able to identify experience elements that can be used to inform future studies, and make recommendations for educators, mentors, and students. In the next sections, we provide a set of considerations for each of these groups based on our findings.

Considerations for Educators and Mentors. Four *experience elements* were commonly identified by participants in our study: Independent Project Work, Project Work that Engages Multiple Disciplines, STEM Education Opportunities, and Mentorship From a Skilled Other. Additionally, one *participant action,* Reflecting on Experience, was commonly identified in our study. As we considered how these *experience elements* and *participant actions* could be incorporated in other engineering curricular and co-curricular contexts, we began with the two *experience elements* that relate to project work.

Independent Project Work and Project Work that Engages Multiple Disciplines. Participants discussed four *competence outcomes* in relation to the two *experience elements* related to project work in our data. Participants linked Business Competence to Independent Projects when they engaged with the *participant action* code Performing Business Analysis. Participants engaged in these actions by performing business-related activities of project work (i.e., project justification using business-related metrics, and considerations of cost when designing experiments). For participants' development of Design Competence through Independent Project Work, the autonomy of decision making appeared to play a big role in students' development of design skills. Similarly, participants described a relationship between Leadership Competence development and their experiences Engaging Multiple Stakeholders in Implementation which was facilitated by the autonomy afforded by Independent Project Work.

In contrast to Independent Project Work, the *experience element* Project Work that Engages Multiple Disciplines necessitates more peer collaboration. Through two different *participant action* codes (i.e., Explaining and Learning Material with Others and

Recognizing Disciplinary Tradeoffs), participants in our study described the development of Interdisciplinary Competence. During our interviews, we asked participants to discuss the interdisciplinary aspects of their BME coursework, as BME has been described as an interdisciplinary field in previous engineering education research (Lattuca et al., 2012); however, participants' discussions of the interdisciplinarity of BME did not demonstrate interdisciplinary competence to the same level as participants' descriptions of their co-curricular experiences with other disciplines.

Summarizing the findings from the identified Project Work *experience elements*, educators should consider assignments or reflections that ask students to consider the business aspects of a product or process they are developing in a design course to develop Business Competence. Some examples of how these activities have been used in engineering courses or co-curricular contexts have been described previously (Andalibi, 2019; Facca et al., 2020; Goldberg, 2007). Educators could also work to incorporate multiple disciplines in student project work in the curriculum to support Interdisciplinary Competence development. Examples of how multiple disciplines have been incorporated into elective curricular project work for engineering students are discussed in Atman and colleagues' (2014) chapter on engineering design education in The Cambridge Handbook of Engineering Education Research (i.e., Purdue's EPICS program and Northwestern University's IDEA model). For co-curricular mentors, one strategy to consider includes opportunities for students to engage multiple stakeholders during their project to support their development of Leadership Competence. Another strategy could be to incorporate localized approaches to multidisciplinary collaboration like encouraging current members to recruit other majors or faculty research mentors encouraging students to work with graduate students in multiple disciplines during their research projects to support the development of Interdisciplinary Competence.

STEM Education Opportunities. Another impactful *experience element* described by participants in our study was opportunities to engage with STEM education positions. The *participant action* codes related to the *experience element* STEM Education Opportunities were very similar; however, participants linked them to different *competency outcomes*. When participants described Disciplinary Competence development related to STEM Education Opportunities, students described opportunities to review, contextualize, or summarize material by preparing course material or teaching their peers about disciplinary concepts through peer-tutoring or instructional aide positions. When participants connected the STEM Education Opportunities *experience element* to Leadership Competence, it was most often in contexts where the participant was serving in a STEM outreach teaching role. Considering these findings, educators may wish to develop in-course opportunities for students to create artifacts or participate in activities that support their ability to review, contextualize, or summarize material with peers. Many of these strategies exist in engineering teaching resources. One example is a recent review on active learning in engineering education by Hernández-de-Menéndez and colleagues (2019) that includes descriptions of learning activities like think-pair-share, one-minute-paper, and the jigsaw method.

Mentorship From a Skilled Other. We also found the importance of the *experience element* Mentorship From a Skilled Other for participants' development of Career Direction Outcomes and Communication Competence. We also saw an indirect relationship between skilled other mentorship and Disciplinary Competence which we will discuss in this section. By soliciting or receiving career goal advice from their internships or directed research mentors or contacts provided by their mentors, participants described developing insights on their Career Direction Outcomes. In our data, we found that the career direction advice from non-peer mentors was a particularly impactful aspect of the mentor-mentee relationship for our BME participants. Similarly, formal and informal mentorship from non-peers has been studied as impactful to the engineering student experience (Atkins et al., 2020; Mondisa & McComb, 2018; Santora et al., 2013). We encourage faculty to consider seeking out resources that can improve and structure their mentorship of direct-report students, or help them advise graduate students on how to structure their mentorship of undergraduate students working on a project. One example of these resources is a recent article by Mondisa, Packard, and Montgomery (2021) that describes STEM mentoring as an ecosystem.

Participants also described having mentors as important for developing Communication Competence. The *participant action* code that connected having a mentor to communication skill development was Participating in Broader Organization Functions which suggests the importance of students' ability to engage with the larger group that the mentor is a part of (e.g., a research lab, a team within a company structure at an internship). Based on the specific *experience elements* that participants linked to communication skills in our data, advisors managing students in co-curriculars should consider the value of including undergraduate students in broader organization functions like lab meetings, project meetings, or socials so they can learn about communication norms and get comfortable talking about disciplinary material. Allowing students to participate in these settings does not have to require large amounts of time or effort on the part of the manager, but has potential for big impact on the student according to our results. Furthermore, our data suggested a nuanced relationship between the *participant action* Participating in Broader Organization Functions and Presenting Disciplinary Material in those settings. When given the opportunity to present disciplinary material to a larger group within the organization they were a part of, participants discussed their increased Disciplinary Competence. Similar to recommendations for developing Communication Competence through mentorship experiences, co-curricular mentors should consider the added value participants discussed as it relates to opportunities to present to the broader co-curricular organization.

Reflecting on Experience. Finally, our data reiterate the importance of reflection for engineering student development already discussed in engineering education literature (Bielefeldt et al., 2011; J. A. Turns et al., 2014). It also links to experiential learning theory (D. A. Kolb, 2015) that emphasizes reflection as an integral part of the cognitive learning process that occurs through experience. Participants described multiple actions that could link to Cultural Competence (i.e., collaborating with a culturally focused major, experiencing another culture, or having formal training through the university) development, but these experiences appeared to require some level reflection on the meaning of the experience for development to be apparent. Similarly, participants were able to describe Career Direction Outcomes through their reflection activities that considered their curricular and co-curricular experiences. To incorporate these findings in practice, we encourage educators and co-curricular advisors to consider structuring periodic opportunities for students to reflect on the relevance of their experiences for their future endeavors. Some engineering education researchers have begun to consider what reflection activities targeting competence development could look like when integrated into engineering education broadly (Sarwari, 2019; Woodcock et al., 2021).

Considerations for Students. Much of our discussion so far has focused on how educators and co-curricular mentors can apply the findings in this study; however, based on the *experience elements* and *participant actions* we identified, we have also developed some recommendations for students considering which co-curriculars to engage with. Based on our study, Mentorship From A Skilled Other was critical *experience element* that facilitated participant experiences leading to both Career Direction Outcomes and Communication Competence. When choosing a co-curricular with a skilled other mentor, students should ask questions about opportunities to gain career advice and participate in activities that will allow them to develop professional skills like Communication Competence. Furthermore, when exploring co-curricular opportunities like directed research or internships for developing Communication Competence or Disciplinary Competence, students should consider whether or not the co-curricular has opportunities to engage with the broader organization or if their main interactions with be with one individual mentor. In instances where participants did not engage more broadly in our data, we saw limited evidence of Communication Competence or Disciplinary Competence development through that co-curricular engagement. Students should also consider opportunities present in these settings when selecting a co-curricular. Presenting opportunities available through directed research supported Disciplinary Competence development in our data. Similarly, students who are choosing co-curriculars with a goal to develop Disciplinary Competence could also consider the value of engaging in opportunities to teach STEM concepts to others (e.g., outreach work, instructional aide work, grader positions, tutoring, etc.). This potential outcome has also been studied in other engineering education research contexts (Pivkina, 2016; Quan et al., 2017). Students can use each of these findings to support decision making related to their co-curricular engagement, helping to support students in choosing a co-curricular opportunity that aligns with their general interests and supports their development goals.

Conclusions and Future Work. Through this exploratory project, we aimed to identify common *experience elements* across co-curricular opportunities that students link to their development of professional competencies. We synthesized data into the *experience elements* presented in our study across a diversity of co-curricular experiences described by the participants (i.e., campus community groups, departmental clubs, project teams, internships, undergraduate research), which we believe provides compelling evidence for the transferability of these results in other contexts. Based on our results, we developed recommendations for educators, mentors, and students to develop competencies. By creating recommendations to incorporate these *experience elements* into curricular efforts, we aim to create opportunities to make the benefits of co-curricular experiences more accessible to students who have fewer opportunities to engage in these spaces. Finally, our work demonstrates the potential contributions of work that deeply examines the learning processes occurring in co-curricular settings. As we continue our work to identify elements of experience that lead to student competence, our goal is to add to the field's understanding of potential pathways students can take through co-curricular engagement to develop professionally relevant competencies.

CHAPTER VII

Discussion: Exploring the Implications for BME Undergraduates

Overview

Across each of the studies in my dissertation, I explored the professional development of BME students. Within the umbrella of professional development, I explored the motivations behind students' BME major choice and decision to engage in co-curricular opportunities as well as professional competency development patterns within those settings. In this chapter, I discuss the intersecting findings of my studies and discuss the overall outcomes.

BME Student Professional Development and Trajectories

Throughout my studies, I found evidence of students connecting their BME degree experiences to their professional development and trajectory. In the data analysis I performed in Chapters 3 and 4, themes relating to BME students' perceived difficulty with the job market beyond graduation were consistent. Many of the participants anticipated entering industry as a long-term career goal (12 of 14 participants), but frequently discussed the need to specialize before doing so. Furthermore, they linked this need to specialize with the broad interdisciplinary nature of their undergraduate degree. Similarly, in Chapter 4, they discussed the how they felt earning a BME undergraduate degree would be perceived. Participants in this study anticipated encountering 1) competition with other engineering disciplines for BME jobs, 2) a need to address the perception that biomedical engineers learn a breadth of disciplinary concepts, but none in depth, and 3) navigation of the breadth of career options for BME graduates. These concerns were highly aligned with longstanding discussions in BME education (Berglund, 2015a, 2015b; Nocera et al., 2018). While the students in my study expressed career concerns in their discussions, they were also able to articulate ways to positively interpret the anticipated hurdles associated with getting a BME undergraduate degree. One example of positive reframing of the breadth of a BME degree that came up in both Chapters 3 and 4 was seeing the disciplinary exposure of BME as a way to explore their interests and keep their career options open even after entering the professional workforce.

Also in Chapter 4, participants were able to articulate unique competency-related aspects of their professional development, describing a set of skills they believe to distinguish the BME degree experience from other engineering degree programs (an ability to understand the human biology context of a problem; communicate across disciplines; bring together multiple disciplinary perspectives; and be open and accepting of the value of collaboration). These skills align with some discussions of the skills employers (e.g., industry employers, academic employers) value from BME graduates (Linsenmeier & Gatchell, 2006; Linsenmeier & Saterbak, 2020; Rivera et al., 2020; White et al., 2020). These results build on the growing literature that suggests both a perceived (Berglund, 2015a) and measurable (Nocera et al., 2018) difficulty for BME undergraduate degree holders to enter industry positions, making research to understand connections between engineering education and industry career placement increasingly important.

Beyond industry placement though, the participants described other career trajectories that can stem from their BME undergraduate degree experience. In particular, participants discussed their degree as valuable for personal reasons, not necessarily linked to attaining careers traditionally considered BME, but rather to their persistence in an engineering degree. Multiple participants discussed the BME degree pathway as a way to study engineering in a context that they find important or interesting, and as they participated in more interviews, began to consider other career pathways. The interview questions that asked students to name possible BME careers could have added to participants' increasing attention to the breadth of career possibilities as they engaged throughout the year-long study; However, some participants demonstrating a higher certainty of their career interests at the beginning of the study showed smaller increases in the number of career paths they named across interviews which indicates that some intrinsic motivation to understand their career interests likely also contributed to the increases seen in this study. Participants' discussions in Chapter 5 demonstrate the broad range of careers these students were considering late into their undergraduate career, and where they learned about career possibilities. Participants discussed possible career paths ranging from academic positions like research or faculty positions to industry positions in biomaterials, bioinformatics, and pharmaceuticals (among many others), and they even discussed non-traditional pathways like consulting, public health, and social work.

These results have implications for how we educate students within a BME degree. As instructors, we can do more to name the career relevant skills students are developing in our classes. Giving students the terminology and skillsets needed to communicate their unique value will serve them in professional interviews and networking opportunities. We can also consider ways to create partnerships between BME employers. One example includes co-op and internship partnerships described in (Waples & Ropella, 2003). We can also work to make connections between the content we are teaching and the careers where that content may be applicable. In Chapter 5, participants emphasized the importance of exploring career options on the development of their views of the overall BME career landscape. Exploration experiences like internships, co-ops, and research opportunities discussed by my participants have been previously implicated as important for BME students' career choices upon graduation (Abu-Faraj, 2008; Ropella, 2003; Waples & Ropella, 2003). However, participants also indicated that smaller career exploration opportunities, like hearing a professor talk about careers in class or during office hours, impacted their career perceptions. Though less studied, this finding aligns with previous research suggesting that students' thoughts about careers can be strongly swayed by a single experience (Lichtenstein et al., 2009). By intentionally developing career exploration opportunities for BME students within courses, we can help students see the breadth of careers available to them as BME graduates, and address some of the career navigation concerns discussed by students in Chapters 3 and 4. Finally, while these single course efforts have potential to positively impact students' career development, programmatic, cross-course efforts that better connect the content students are learning in their classes to the work they will perform in their careers. As a few examples, these efforts could look like coordinated career-related reflection activities across courses, short assignments that link content to relevant careers in each course, or seminars that engage alumni across a spectrum of career paths.

BME Students' Motivations to Participate in Co-Curricular Experiences

I saw similar patterns of professional skills development and professional trajectory outcomes in the chapters that explored students' co-curricular participation. In Chapter 3, MDE and undergraduate research participants discussed personal motivations for engaging with co-curriculars that they assigned attainment and interest values to. Participants valued their co-curricular experiences because they helped them connect their identity to their major or department (attainment value) and allowed them to explore what they enjoyed about BME (interest value). Most frequently, MDE participants talked about attainment value. They discussed the importance of having a community where they felt they belonged and doing work that helps others. As I gathered more data in this study, I began to see evidence of other co-curricular settings where students described similar attainment value motivations. In Chapter 6 I analyzed the data to identify experience elements that might lead to professional outcomes. In doing so, I found that mentorship from a skilled other (e.g., in research, co-ops, internships) could support students' career directions outcomes. Participants also described developing personal attributes in line with the SVT construct attainment value. Through repetition of exposure to disciplinary practices in their various co-curricular opportunities, participants gained self-confidence in their abilities as engineers.

In slight contrast with MDE participants, research participants discussed the interest value dimension of their co-curricular participation more frequently. They talked about the value they placed on opportunities to explore their research interests and perform research tasks that they found intellectually stimulating. However, the attainment and interest values of research participants in Chapter 3 point to some of the same outcome development patterns discussed in Chapter 6 that I linked to MDE attainment and interest motivations (e.g., career direction and personal attribute outcomes).

While MDE and research participants emphasized attainment and interest value motivations to different degrees, both groups frequently discussed utility value motivations. In Chapter 3, I found that BME students are motivated to engage in co-curriculars that they believe to have opportunities to build skills, create connections, and get career advice which can improve their career outlooks. Bringing in what I learned in Chapter 6 regarding professional competency development patterns, we can use what know about student motivations to participate and student participation outcomes to develop experiential learning opportunities. Designing the opportunities can be based on what we already know influences students to engage as well as on the potential professional competence development benefits of participation.

In Chapter 3, I found that MDE participants valued opportunities to develop professional competencies like communication, leadership, teamwork, disciplinary, and design competence. Looking at the longitudinal data from multiple co-curricular types in Chapter 6, participants discussed experience elements and actions they took to develop these competence outcomes. Participants in my study identified four experience elements they linked to development of Communication Competence (i.e., Regular Organization Meetings, Mentorship from a Skilled Other, Networking Opportunities, and Academic Publishing or Presenting). They identified three experience elements relevant to Leadership Competence Development (i.e., Independent Projects, Peer Team Participation, and STEM Education Opportunities). Participants also linked Independent Project work to their Design Competence development along with the experience element Early-Stage Project Work. Furthermore, they linked the experience element Team Hierarchy or Roles to developing Teamwork Competence and three experience elements to Disciplinary Competence (i.e., Disciplinary Contextualization, Participating in Broader Organization Functions, and STEM Education Opportunities). Similarly, as reported in Chapter 3, research participants discussed utility value in the formal recognition they gained through papers and presentations as well as in knowing people who had already navigated graduate school. In addition to the Communication

Competence development that I discussed in Chapter 6, these utility value motivations may link to Career Direction Outcomes that occurred through the experience element Mentorship from Skilled Other, which I also reported in Chapter 6.

The findings in Chapters 3 and 6 provide examples of how engagement (Astin, 1984; Mayhew et al., 2016; Pace, 1998) and EL (A. Y. Kolb & Kolb, 2008; D. A. Kolb, 1984, 2015; David A. Kolb et al., 2011) opportunities can motivate and support BME students' professional development. They also corroborate previous research that discusses the importance of co-curricular learning opportunities in engineering education (Burt et al., 2011; Busby, 2015; Fiorini et al., 2014; Fisher et al., 2017; Litchfield et al., 2016; Young et al., 2015). However, depending too heavily on co-curricular learning to develop these professional competencies in students creates concerns about equity, access, and diversity in engineering. Recent studies have found differences in co-curricular participation based on demographic backgrounds of students. In particular, one broad study on undergraduate students found that male students, Asian American students, older students, first-generation students, and students without future educational plans were less likely to participate in internships (Hoekstra, 2021). Another study compared out-of-class participation of engineering students at an R1 university and the authors' primarily undergraduate university, and found differences in the types of activities valued by students and the motivations students might have for participating (Oliver et al., 2021). These studies indicate the importance of understanding differences in the populations that participate in co-curricular experiences and could have implications for how educators recruit and retain students in co-curricular experiences. By acknowledging that there are learning benefits (e.g., professional outcomes, disciplinary skills development, etc.) but not paying attention to the types of students participating and why, we are missing opportunities to promote equity of experience and remove potential barriers to participation.

Considerations for educators. Although identified through a study of BME students' co-curricular experiences, the study results reported in Chapter 3 and Chapter 6, suggest ways to incorporate experience elements in curricular offerings for BME students. Summarizing the takeaways from the project work, STEM education, and mentorship from a skilled others that I identified, I would encourage educators to consider incorporating and then explaining the potential competency outcome benefits of the following activities:

- Assignments that ask students to consider the business aspects of a project they are developing in a design course with the goal of developing students' Business Competence. Examples of how this have been done have been described by Andalibi (2019), Facca et al., (2020), and Goldberg, (2007).
- Student project work that engages multiple disciplines to support Interdisciplinary Competence development. Examples of how multiple disciplines have been incorporated into elective curricular project work for engineering students include Purdue's EPICS program (*EPICS*, n.d.) and Northwestern University's IDEA model (Mckenna et al., 2006).
- Project work that requires students to engage multiple stakeholders (i.e., requiring input from individuals who are not part of the course where the project takes place) to support their development of Leadership Competence.
- Opportunities for students to create artifacts or participate in activities that allow them to review, contextualize, or summarize material with peers to support Disciplinary Competence development. Interested educators should consider a recent review on active learning in engineering education by Hernández-de-Menéndez and colleagues (2019) that includes descriptions of learning activities like think-pair-share, one-minute-paper, and the jigsaw method.
- Opportunities for student-researchers to participate in broader organization functions like lab meetings, project meetings, or socials to support their development of Communication Competence and Disciplinary Competence. I found that allowing students to participate in these settings taught them about communication norms, increased their comfort in talking about disciplinary material, and encouraged deeper learning of disciplinary material.
- Structured opportunities for students to reflect on what their current experience means in future engineering settings. Sarwari (2019) provides an example of what this might look like in engineering courses.

By explaining to students how these experience elements might lead to the outcomes identified in my studies, we can leverage the utility value motivations of students to improve their engagement and subsequently support their learning. I do not think it is reasonable to incorporate all of the beneficial elements of co-curricular learning into students' coursework due to instructor and class time, resource, and other considerations that impact course design (see (Lattuca & Stark, 2009) for a discussion of possible considerations when creating a course). However, I do believe that creating more of these learning opportunities in classrooms ensures that students with fewer opportunities to engage in co-curriculars a have a more equitable opportunity to succeed in engineering.

Considerations for students. My work in Chapter 6 also provides recommendations for BME students who want to be more intentional with the co-curriculars in which they engage. By providing those recommendations, it is my goal to support engineering students who cannot participate in multiple co-curricular opportunities at a time, or have a limited amount of time or resources they can commit each semester to these opportunities. Based on the experiences of the students in my study, mentorship from a skilled other was critical *experience element* that facilitated the development of Career Direction Outcomes and Communication Competence. I encourage students to ask questions about what mentorship will look like in co-curriculars where they will be working with a mentor. I encourage questions that will help them understand if there are opportunities to gain career advice, participate in broader organization activities like lab meetings or project team meetings, or present their work to a larger group for feedback or discussion; each of these experiences reportedly led to student professional competency outcomes in Communication and Disciplinary Competence as well as Career Direction Outcomes. Furthermore, students who are choosing co-curriculars with a goal to develop Disciplinary Competence could also consider the value of engaging in opportunities to teach STEM concepts to others (e.g., outreach work, instructional aide work, grader positions, tutoring, etc.). Students can use each of these findings to support decision making related to their co-curricular engagement, helping to support students in choosing a co-curricular opportunity. As my research continues I aim to make more connections like these that can contribute to a robust set of recommendations for both educators and students.

Conclusion

Overall, the results of my studies provide actionable items for educators to consider in order to support BME student professional formation and learning. Furthermore, this research gives BME students tools to make informed decisions about their engagement in co-curricular opportunities, and sets up a research agenda for the future. In Chapter 8, I discuss ideas for future work in three areas: BME experiential education, co-curricular learning processes, and engineering professional development and preparation.

CHAPTER VIII

Future Work: Exploring Future Avenues for Research

While my dissertation contributes to our understanding of students' professional formation through co-curricular and EL opportunities, there are many research areas I believe need further exploration. Overall, my future work will focus on contributing knowledge to diversity, equity, and access issues associated with BME education, co-curricular and EL opportunities, and professional development and career preparation processes.

BME Education

The results of my work in Chapter 4 indicated opportunities to explore ways to recruit diverse student populations. In particular, three participants holding one or more marginalized identities in engineering discussed motivations to pursue BME as a way to complete an engineering degree in a context they found compelling (i.e., directly helping others) or interesting (i.e., biological concepts) enough to keep them in the degree through graduation. This finding is interesting in that these motivations for pursing engineering partially relate to the narratives about improving diversity in engineering found by Sochacka and colleagues in their recent study (Sochacka et al., 2021). Their study analyzed public discourse (i.e., online news articles from a news briefing service for engineering educators) on engineering in the United States (US) to explore views of diversity in engineering and proposed solutions to improve the field's diversity. They found that discussions around diversifying engineering in these articles mainly view diversifying engineering as solving an issue related to the US' economic recovery and competitiveness. The paper also described five themes of recommendations to address diversity concerns according to the news articles studied:

- Getting students excited about and proficient in math and science

- Exposing students to ‘hands-on’ aspects of engineering
- Better explaining to the public what engineers do
- Harnessing and/or celebrating the creative potential of a diverse population
- Encouraging students through the hard work it takes to “make it through” engineering degrees

Sochacka and colleagues also provide critique to the common narrative found in the articles they studied, noting that the emphasis on competition, economic gain, and technological design impact efforts to attract and retain students in engineering. In my future research, I would like to similarly explore the potential differences in the stories BME students have for entering a BME major, persisting in the major, and pursuing a BME career. By exploring a major that has relative success in recruiting and retaining women in the major (American Society for Engineering Education, 2020), we might find stories that align more with what students holding marginalized identities in engineering prioritize in an engineering major or career. In particular, I am interested in exploring three elements of recruitment and retention of diverse populations (e.g., women, racial/ethnic minorities, first-generation, students with disabilities) in BME.

1) How do students come to know about BME as a major?
2) Why do students decide to pursue BME?
3) Why students stay or leave the major during their undergraduate experience?

Understanding these elements of student decision-making can help educators understand how programs can better recruit and subsequently support diverse student populations. Furthermore, because recent research indicates that students may not pursue engineering jobs upon graduation (Gilmartin et al., 2015; Lichtenstein et al., 2009; J. A. Rohde et al., 2019), I would also like to look for patterns in how diverse students exit a BME degree program, paying particular attention to what careers they pursue and why. These studies can give us insights into what supports students holding marginalized identities might need to feel they belong and can succeed in BME. Beyond BME, asking questions about what is attracting and retaining students in this way could start to understand

Co-Curricular Learning Processes

In Chapter 3, I identified limited cost considerations that students associated with their co-curricular participation. Contrary to the other dimensions of subjective task value, cost is a dimension that accounts for potential negative impacts of engaging in a task, which, in this study, was the MDE or research co-curricular. The main cost consideration finding was that students acknowledged that co-curricular participation took a lot of time. Because studying motivations for participating in co-curriculars was not the main goal of my research, I did not include non-participants in my study sample. In future studies, I would like to incorporate students who have left a co-curricular opportunity or have limited co-curricular participation to explore potential differences across their perceptions of attainment (i.e., supporting aspects of their identity), interest (i.e., enjoyment of the tasks), and utility (i.e., usefulness for future goals) values of co-curricular experiences as well as identify other perceived costs they might view as barriers to participation. Understanding the differences in the values that students attribute to co-curricular participation based on type of co-curricular (e.g., research, design teams, outreach, etc.) and the background of the students is important for improving co-curricular engagement more broadly. By identifying the differences in motivations for participating, institutions can work towards support structures (e.g., resources, programs to provide guidance) that allow students to more purposefully choose to participate in co-curriculars that align with their values in addition to lowering or eliminating the potential barriers to participation. Creating resources that provide selection guidance, engagement advice, or financial support to students who may not otherwise by able to participate in depth due to commitments like jobs to pay tuition, childcare, or other familial duties can also further our efforts to support access to co-curricular participation. I would like to see this work expand to disciplines outside of BME as well, exploring potential differences in the motivational values that students in other engineering disciplines associate with their co-curricular engagement.

In Chapter 6, I identified elements of experience and participant actions important for professional competence development. In the future, I would like to see this research expanded to other engineering disciplines and co-curricular contexts to understand if and how my findings might align or differ from studies conducted in those spaces. As we, as a field, begin to deepen our understanding of how the professional learning processes occur, I want to explore how learning theory can be leveraged to first understand how learning is occurring, and second develop pedagogical approaches to supporting similar learning processes in engineering classrooms. For example, I might explore how cognitive frameworks (e.g., social cognitive theory or constructivism) or situated frameworks (e.g., communities and landscapes of practice, distributed cognition) can provide greater understanding of the learning experiences of students in a given co-curricular activity. I would then aim to develop strategies to emulate that learning process in a course. These efforts align with and will subsequently add to how Newstetter and Svinicki provide examples of how instructors might develop pedagogy that leverages learning theories in Chapter 2 of the 2014 Cambridge Handbook of Engineering Education Research (Newstetter & Svinicki, 2014) by studying learning processes in co-curriculars to inform the development of pedagogical approaches. I believe these efforts to map beneficial elements of co-curricular experiences to classroom learning will help us support students who have limited access to co-curricular opportunities, supporting equity efforts in engineering.

Engineering Professional Development and Preparation

I would also like to work to connect academic institutions' understanding of professional formation and preparation to industry expectations. In BME in particular, some of the career search difficulties experienced by students have been attributed to a disconnect between what is taught in the degree program and what is expected in the job responsibilities (Linsenmeier, 2003; Ramo et al., 2019). As we begin to better understand how professional learning is occurring for students, it will be important to also understand how the competencies we are developing in students align with employer expectations. I have begun to explore questions in this space for BME students (C. S. E. Jamison, Vempala, et al., 2021), and I am looking forward to developing studies that engage industry and other BME employers to understand the landscape of BME practice. Recent research has already begun to explore ways to make hiring practices more transparent, and support the job search processes of software engineers (Behroozi et al., 2020). In line with this study's goals, I also believe clarifying BME employer expectations will further assist employers in finding employees that are a good match for their companies and support the BME profession in creating a more equitable and diverse community. Because BME is a constantly evolving field, the needs of employers will similarly evolve, highlighting the need for educators to acknowledge and account for these changes as they develop and modify BME curriculum over time.

APPENDIX

Table A. 1. References of articles included in full review. Articles are organized by date of publication and alphabetically by title.

2010	
A Project-Based Laboratory for Learning Embedded System Design with Industry Support	(C.-S. Lee et al., 2010)
A Service Learning Structural Engineering Capstone Course and the Assessment of Technical and Non-Technical Objectives	(Dinehart & Gross, 2010)
Closing the Competency Gap in Manufacturing Processes as It Applies to New Engineering Graduates	(Ssemakula et al., 2010)
Engineering Math Based Bridge Program for Student Preparation	(Boykin et al., 2010)
I Thought This Was Going to Be A Waste of Time How portfolio Construction can Support Student Learning from Project-Based Experiences	(J. Turns et al., 2010)
The Difficult Bridge Between University and Industry: A Case Study in Computer Science Teaching	(Schilling & Klamma, 2010)
2011	
A Cochlear Implant Signal Processing Lab: Exploration of a Problem-Based Learning Exercise	(Bhatti & McClellan, 2011)
Case Study of a Project-Based Learning Course in Civil Engineering Design	(Gavin, 2011)
Motivation and Engagement of Learning in the Cooperative Problem-Based Learning (CPBL) Framework	(Mohd-Yusof et al., 2011)
Nurturing Creativity and Innovative Thinking through Experiential Learning	(Ayob et al., 2011)
Student Development in the Co-curriculum through Values-Based Teaming	(Dolan et al., 2011)
Using LEGO NXT Mobile Robots with LabVIEW for Undergraduate Courses on Mechatronics	(Gomez-de-Gabriel et al., 2011)
Using Portable Electronics Experiment Kits for Electronics Courses in a General Engineering Program	(Yao et al., 2011)
Vertical Stream Curricula Integration of Problem-Based Learning Using an Autonomous Vacuum Robot in a Mechatronics Course	(Chin & Yue, 2011)
2012	
A Summer Leadership Development Program for Chemical Engineering Students	(Simpson et al., 2012)
Centrifugal Pump Experiment for Chemical Engineering Undergraduates	(Vanderslice et al., 2012)
Creativity Enhancement through Experiential Learning	(Ayob et al., 2012)
Empirical Analysis of Effect of Project-Based Learning on Student Learning in Transportation Engineering	(Fini & Mellat-Parast, 2012)
Engineering in Communities: Learning by Doing	(Goggins, 2012)
Evaluating the Effectiveness of Problem-Based Learning (PBL) Implemented in the Textile Engineering Course	(Baral et al., 2012)
Exploring an Experiential Learning Project through Kolb's Learning Theory Using a Qualitative Research Method	(Chan, 2012b)
Finite Element Learning Modules as Active Learning Tools	(Brown et al., 2012)

Improving Students Understanding of Engineering Concepts through Project Based Learning	(Jackson et al., 2012)
Integrating Innovation Skills in an Introductory Engineering Design-Build Course	(Liebenberg & Mathews, 2012)
PBL: An Evaluation of the Effectiveness of Authentic Problem-Based Learning (aPBL)	(Woods & Woods, 2012)
Six Hands-on Activities Designed to Improve Student Achievement in and Attitude Towards Learning Fluid Mechanics	(Albers & Bottomley, 2012)
What Value Does Service Learning Have on Introductory Engineering Students' Motivation and ABET Program Outcomes?	(Sevier et al., 2012)
2013	
A Hands-on Project-Based Mechanical Engineering Design Module Focusing on Sustainability	(Joyce et al., 2013)
Facilitating Higher-Order Learning Through Computer Games	(Siddique et al., 2013)
Factors Affecting Perceived Learning of Engineering Students in Problem Based Learning Supported by Business Simulation	(Chaparro-Pelaez et al., 2013)
Implementing Co-operative Education in an Industrial Engineering Program	(Brahimi et al., 2013)
Implementing Problem Based Learning through Engineers without Borders	(Wittig, 2013)
Physical Student-Robot Interaction with the ETHZ Haptic Paddle	(Gassert et al., 2013)
2014	
Personnel improvement plan: A professionalism assignment for engineering students	(Habibi et al., 2014)
2015	
A Course on Digital Electronics Based on Solving Design-Oriented Exercises by Means of a PBL Strategy	(Jordana & Robert, 2015)
A Multidisciplinary PBL Robot Control Project in Automation and Electronic Engineering	(Hassan et al., 2015)
Application of Problem-Based Learning to Teaching the Critical Path Method	(Forcael et al., 2015)
Design and Implementation of a Microcontroller Based Workstation with Educational Purposes for the Control Systems Area	(Patarroyo et al., 2015)
Development of the Whole Student through an Engineering Abroad Service Learning Program: Rainwater Catchment/Filtration System in Guatemala	(Panzardi et al., 2015)
Does Curriculum Practical Training Affect Engineers' Workplace Outcomes? Evidence from an Engineer Survey in China	(Li et al., 2015)
Enhancing Students' Problem-Solving Skills through Progressive Integration of Project-Based Learning	(Jackson & Tarhini, 2015)
Impacts of Service-Learning Projects on the Technical and Professional	(Siniawski et al., 2015)
Longitudinal Assessment of Student Persistence, Achievement, and Attitude in a Flipped Biomedical Engineering Classroom Using Pencasts and Muddiest Point Web-Enabled Tools	(Ankeny & Krause, 2015)
Peer-led Team Learning in Early General Engineering Curriculum	(Lewis et al., 2015)
Sort Attack: Visualization and Gamification of Sorting Algorithm Learning	(Yohannis & Prabowo, 2015)
The Effect of Project Constraints and Choice on First-Year Microcontroller Projects	(Shepard et al., 2015)
2016	
A Project-Based First Year Electrical and Computer Engineering Course: Sensor and Telemetry Systems for High-Altitude Balloons	(Thomas & Theriault, 2016)
A Senior Project-Based Multiphase Motor Drive System Development	(Abdel-Khalik et al., 2016)
Automated Multiparameter Water Monitoring System as an Experiential Learning Platform for Undergraduate STEM Majors	(Henry et al., 2016)
Developing Student Outcomes in Real-World Learning Experiences: The Case of Solar Decathlon in Latin America	(Ortegon, 2016)

Enhancing Project-Based Learning Through Student and Industry Engagement in a Video-Augmented 3-D Virtual Trade Fair	(M. J. W. Lee et al., 2016)
Improving Student Learning Experience via Extracurricular Undergraduate Research in Near-Space Ballooning	(W. Lee & Conklin, 2016)
Improving the Impact of Experiential Learning Activities through the Assessment of Student Learning Styles	(M. Johnson et al., 2016)
Long-term Impact of an Elective, First-Year Engineering Design Course	(Torres et al., 2016)
Project-Based Introduction to an Engineering Design Course Incorporating Microbial Fuel Cells as a Renewable Energy Technology	(Gadhamshetty et al., 2016)
Project-Based Learning for Electrical Engineering Lower-Level Courses	(Song & Dow, 2016)
Simprogramming: The Development of an Integrated Teaching Approach for Computer Programming in Higher Education	(Pedrosa et al., 2016)
Technical and Professional Skills of Engineers Involved and Not Involved in Engineering Service	(Litchfield et al., 2016)
The Impact of Experiential Learning Methodology on Student Achievement in Mechanical Automotive Engineering Education	(Giridharan & Raju, 2016)
2017	
Benefits for Undergraduates from Engagement in an Interdisciplinary Environmental Monitoring Research and Education Lab	(Basu et al., 2017)
Community Service as a Platform for Environmental Ethics in Citra Education	(Zain et al., 2017)
Evaluation of Creative Problem-Solving Abilities in Undergraduate Structural Engineers through Interdisciplinary Problem-Based Learning	(McCrum, 2017)
Improved Learning through Collaborative, Scenario Based Quizzes	(Oishi et al., 2017)
Miniaturized Inexpensive Hands-on Fluid Mechanics Laboratory Kits for Remote Online Learning	(Starks et al., 2017)
Molding the Interactive Flipped Classroom Based on Students' Feedback	(Al-Hammoud, 2017)
Problem and Project-Based Learning in Scripting Lab	(Giraddi et al., 2017)
Project Based Learning Using the Robotic Operating System (ROS) for Undergraduate Research Applications	(Wilkerson et al., 2017)
Project-Based Learning Approach: Improvements of an Undergraduate Course in New Product Development	(Zancul et al., 2017)
Using PBL to Improve Educational Outcomes and Student Satisfaction in the Teaching of DC/DC and DC/AC Converters	(Martinez-Rodrigo et al., 2017)
Webcasts Promote In-Class Active Participation and Learning in an Engineering Elective Course	(Freguia, 2017)
2018	
A Multidisciplinary Industrial Robot Approach for Teaching Mechatronics-Related Courses	(Garduño-Aparicio et al., 2018)
Case Study on Community-Based Learning: Toy Design Project for Children in Egyptian Squatter Community	(El-Gabry, 2018)
Collaborative Approach in Software Engineering Education: An Interdisciplinary Case	(Vicente et al., 2018)
Effective Approach in Making Capstone Project a Holistic Learning Experience to Students of Undergraduate Computer Science Engineering Program	(Deepamala & Shobha, 2018)
Elevating Learner Achievement Using Formative Electronic Lab Assessments in the Engineering Laboratory: A Viable Alternative to Weekly Lab Reports	(Chen et al., 2018)
Engineering Students Can Use the Words ‘Calculus’ and ‘Love’ in the Same Sentence: Using Active Learning the Impossible Can Happen	(Cuzzuol et al., 2018)
Experiment-Centric Pedagogy in Circuits and Electronics Courses	(Connor et al., 2018)
Exploratory Study of the Acceptance of Two Individual Practical Classes with Remote Labs	(Tirado-Morueta et al., 2018)
Flipped Classroom Using ICT tools To Improve Outcomes for the Course	(Kavitha & Anitha, 2018)

Implementing Collaborative Projects Using a National Academy of Engineering (NAE) Grand Challenge: Provide Access to Clean Water	(Wright et al., 2018)
Implementation of a Project Based Learning Approach to Undergrad	(Elahi, 2018)
Increasing Student Self-Efficacy through Undergraduate Research Experiences: A Qualitative Study	(Litton et al., 2018)
Scaffolding to Support Problem-Solving Performance in a Bioengineering Lab - A Case Study	(Clark & Mahboobin, 2018)
Use of Multimedia for Experiential Learning in Engineering Techniques	(Geng & Alani, 2018)
Using Distinctive Student Engagement Elements in a Technical Elective Course	(Rayegan & Lewis, 2018)
Using LEGO Kits to Teach Higher Level Problem Solving Skills in System Dynamics: A Case Study	(Wu et al., 2018)
2019	
Analyses of Possibilities of Flipped Classroom in Teaching Computer Science Courses	(Fetaji et al., 2019)
Applied Knowledge Retention - Are Active Learning Tools the Solution?	(Acharya et al., 2019)
Developing and Assessing Engineering Competencies at Experiential Learning Spaces	(Garay-Rondero et al., 2019)
Engagement-in-Practice: CAD Education via Service-Learning	(Che, 2019)
Engineering Leadership Development Using an Interdisciplinary Competition-Based Approach with Cross Functional Teams	(Bayless, 2019)
Improving Program Outcome Attainments Using Project Based Learning	(Patange et al., 2019)
Learning by Doing: Collaborative Active Learning Hands-on Project-Based Homework for a Large Gateway Engineering Class	(Zaurin, 2019)
Learning-by-Doing: The Chem-E-Car Competition® in the University of Cantabria as a Case Study	(Dominguez-Ramos et al., 2019)
Mapping Engineering Students' Learning Outcomes from International Experiences: Designing an Instrument to Measure Attainment of Knowledge, Skills, and Attitudes	(Zhu et al., 2019)
Measuring the Impact of Experiential Learning	(Callewaert, 2019)
Project Based Guided Learning for Machine Elements Design Course	(Shehadi, 2019)
Research-Based Learning: A Case Study for Engineering Students	(Noguez & Neri, 2019)
The Effectiveness of Problem-Based Learning in Technical and Vocational Education in Malaysia	(Jabarullah & Iqbal Hussain, 2019)
2020	
Service Learning Experiences from the Lens of Student Outcomes and Willingness of Engineering Students' Community Involvement	(Laguador & Chavez, 2020)

Table A. 2. Possible career path codes and definitions.

Category	Subcategory	Description
Academia Employment at an academic institution.	*Academic Advising*	Provide students with educational and professional support. This includes helping students explore their academic interests, developing plans of study, and connecting students with resources for additional information and support.
	Education	A professor or faculty member at an academic institution
	General	References to academia as a career path without specification of a subcategory
	Research	Conducts studies and experiments with the aim of developing a greater level of understanding on the subject matter
Industry Careers involving the design,	*Bioinformatics*	Utilizes computational research methods and software to explore biological and genetic data
	Biomaterials	Specializes in the development of synthetic materials for use in biological systems

manufacturing, regulation, and sale of products and services in the biomedical sector.	*Design, Research & Development*	Responsible for the design and iteration of new products and systems for a company. This includes need assessment, design iteration, testing prototypes, and mentions of research with the goal of designing products, etc.
	General	References to industry as a career path without specification of a subcategory
	Human Factors, IOE	Involved in the design of machines, systems, and environments to allow for safe and effective use.
	Medical Devices	Jobs pertaining to the production and sale of medical devices. This includes prosthetics and other instruments that aid medical providers in the diagnosis and treatment of disease.
	Operations	Responsible for ensuring that the operations within a company are working properly and efficiently.
	Pharmaceuticals	Involved in the production and sale of medication and pharmaceutical drugs.
	Regulatory, Quality Engineering	Responsible for inspecting equipment and product safety, developing quality standards, and implementing quality control measures.
Other	*Business*	Roles in sales, human resources, PR, finance, accounting, marketing, and more.
	Coding, Computational	Utilize technical skills to solve computing problems or develop new softwares and programs.
	Consulting	Offer advice to organizations on methods to improve their business performance.
	Dental	Provides care for patients to ensure that their teeth and mouth are healthy.
	Healthcare	Jobs involving an active role in a clinical setting. Includes references to attending medical school, nursing, clinical engineering, etc.
	Management	Responsible for the recruitment, training, and management of a team or staff. Includes project manager roles in industrial settings.
	Other Engineering	References to other disciplines of engineering or roles traditionally filled by engineers belonging to other disciplines. Includes chemical, electrical, mechanical, and data engineering as well as neuroengineering.
	Patent, Law, Politics	Employment at a governmental institution or careers in public policy, legal and governmental affairs, or politics.
	Public Health	Careers that aim to improve the health of the community as a whole. Includes epidemiology, global health, biostatistics, etc.
	Social Work	Assist clients with everyday life problems and may also diagnose and treat patients with mental, behavioral, and emotional issues.
	Veterinarian	Diagnose, provide treatment for, and conduct research on illnesses and injuries of animals.

Table A. 3. Possible career path codes raw counts (Note: underlined = totals).

	Interview 1 (n=14)	***Interview 2 (n=14)***	***Interview 3 (n=13)***
Academia	**11**	**11**	**10**
Academic Advising	0	1	0
Education	2	4	3
General	1	2	2
Research	8	4	5
Industry	**28**	**43**	**38**
Bioinformatics	1	1	1
Biomaterials	1	2	0

Design, Research & Development	10	10	8
General	3	7	6
Human Factors, IOE	0	1	1
Medical Devices	7	10	11
Operations	0	1	1
Pharmaceuticals	5	6	5
Regulatory, Quality Engineering	1	5	5
Other	**30**	**58**	**37**
Business	1	3	5
Coding, Computational	1	3	1
Consulting	4	6	2
Dental	0	3	0
Healthcare	7	12	8
Management	1	3	4
Patent, Law, Politics	0	4	4
Public Health	1	3	3
Social Work	1	1	2
Veterinarian	0	1	0
Other Engineering	*14*	*19*	*8*
Chemical	2	5	1
Data Engineering	0	1	1
Electrical	4	3	3
General	0	3	0
Mechanical	8	6	3
Neuroengineering	0	1	0
Total Number of Codes	**69**	**112**	**85**

Table A. 4. Semi-structured interview example questions.

Background	Can you talk about the BME courses you took this semester?
	Did you enjoy the content of those courses? Why?
	Did you enjoy the way it was taught? Why?
	Is there anything you took away from these courses that you think is preparing you for a career in BME?

Last time we talked we were talking about your work in [research or MDE]. Can you give me an overview of what you have been doing?

What about the specific project you've been working on in [research or MDE]? How is that project going? What have you accomplished on it this semester?

- What are you currently doing on the project?
- Do you feel like the goals of the project have changed since we last talked? How?

Are you on a new project?

- What are you currently doing on that project?
- What is the purpose of that project?

Were there ever any different/conflicting perspectives and expertise on the team this semester? Or with others you engaged with during your work?

I consider anyone who has an interest in the project to be a stakeholder, so knowing that, who are your stakeholders?

How did you communicate with those stakeholders this semester?

- Did communication look different based on the stakeholder?
- What do you think you've learned about communicating with different stakeholders?
- What are some strategies you have taken away from those experiences? What has been helpful in developing those strategies?

Do you feel like your engagement with the project has changed since we last talked? How?

- Has your role in the project changed? How?

How will you know if your project is successful?

- What would make the [experience or project] successful for you personally?
- What would make the [experience or project] successful for your professional goals?

If you were at a technical conference in your field and you had to present this work at a poster session in a minute, what would you say about it?

Now imagine giving a one minute description to your friend in a major outside of engineering or science, what would you say about your project?

- Do you feel like your description changed?
- (If Y) How did it change? Why did you change it?
- (If N) Why not?

Can you tell me about a time in your project this semester when you had to work with people in a different engineering or science major? What was that like?

- What aspects of that interaction did you find helpful? Was there anything you found not helpful? Why?
- What did you do, or what could you have done to help make that experience better?

Development

Career Preparation

Based on your experience so far at [Midwest University], what would you say are your professional aspirations immediately after getting your bachelor's degree? In 5 years? In 10 years?

- Have these plans changed since you started at [Midwest University]? How?

Based on your experiences at [Midwest University], what is the range of careers do you think BME's can have?

Thinking about what you have gotten out of [Research and/or MDE], what BME career preparation do you have without it?

- Where would you say you got exposure to that [skill, concept, ability]?

How is your experience in [Research and/or MDE] helping you reach your professional goals in BME?

- Is there anything about your experience that is not helping you reach your goals?

Have any other experiences you've had at [Midwest University] been helpful in preparing you for your professional goals?

- What aspects of the experience have been helpful?
- Why did you decide to participate in that experience?

How would you describe the value of your BME degree?

What do you think makes students in the BME major unique?

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